SEAWEEDS AND THEIR USES

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AND THEIR USES

BY

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TO MY WIFE

PREFACE

THE recent war forced the Allied countries to seek alternative sources of raw materials and, as in the first world war, attention was paid by all belligerents to the marine algae or seaweeds. These occur in considerable quantities in various parts of the world, and attempts to make use of this cheap and readily accessible, though not so readily harvestable, raw material have been made almost from time immemorial. Much of the work on the economic utilisation of seaweeds has been published only in scientific journals and has never been collected within the compass of a single book. Tressler's work on *The Marine Products of Commerce* contains three useful chapters on this subject, whilst Sauvageau's book, *Les utilisations des Algues Marines*, is a mine of valuable information, especially as regards the use of seaweeds in France. Both these volumes are, however, somewhat out of date, Tressler's being published in 1923 and Sauvageau's in 1920. Furthermore there is no book wholly on this subject in the English language, and so the present volume has been undertaken in order to fill this gap. The opportunity has also been taken to incorporate the results of researches carried out since 1920. In certain aspects of the subject it will be found that considerable advances have been made, and in the present volume particular reference to such advances will be found in the chapters on agar and alginic acid.

This book has been written not only for those with technical knowledge but also for the general reader. It is hoped that sufficient information has been introduced to make it of value to the former class of person, whilst not burdening it unduly to make it unreadable to the second category. For the benefit of those who want to study any aspect in more detail the bibliography has been made as complete as possible.

The subject matter refers solely to the algae, and therefore the economic uses of the marine phanerogams have not been considered. The reason for this decision is that, compared with the algae, the marine phanerogams do not occupy such an important position.

When consideration has been given to all the different methods throughout the centuries whereby mankind has endeavoured to

make use of the seaweeds, and a survey has been made of the sorry sequence of failures and abortive efforts, the question "Why have the industries failed?" comes foremost. The supply of raw material is vast and inexhaustible, and yet there is really no flourishing industry other than in Japan. There are, I think, various reasons that provide an answer to this question, and in answering it, one may also tentatively suggest the requisite conditions for the establishment of an economically successful industry. The recent formation of the Scottish Seaweed Research Association (Anon., 1944) may be regarded as one step in the right direction.

The following causes appear to have contributed generally towards the failure of past enterprises in Europe and America. The primary cause has been the restriction of the enterprise to one aspect only, e.g. production of iodine, production of a manure or of a cattle feed, or production of alginic acid compounds. Alternatively, attempts to make use of by-products were unsuccessful because the chemical processes employed led to uneconomic results. In Europe another important general contributory cause has been the failure, so far, to evolve a cheap means of harvesting. It is the cheapness of the labour in Japan that has enabled the industry in that country to flourish. Cheap labour will never be obtainable in Europe and therefore the development of efficient mechanical harvesting is a first essential.

It is perhaps pertinent to attempt some analysis of the individual industries. Thus the kelp industry in Europe failed because it could not compete with iodine and sodium salts manufactured from other sources. The answer is comparatively simple: the methods of production were inefficient and the chemical processes produced by-products that were not pure enough. Far too often a seaweed industry has been erected upon the success of laboratory experiments and trials, and then subsequently it has been found that the laboratory methods, when applied on an industrial scale, do not yield products of the necessary commercial purity. Such failure has spelt the death of the company before it has become established.

The Pacific coast kelp industry failed because it was conceived as a war-time industry when finance was immaterial. Under peace conditions the methods of production were far too costly. The agar industry gravitated naturally to Japan because the type of weed they used and their method of preparation produced such an excellent and cheap commodity that there seemed little reason for other countries to spend money on finding alternative

supplies, which would probably only have yielded a more expensive material. Industries associated with alginic acid have never been wholly successful from the very start, on account of undue optimism, uneconomic methods of harvesting and a failure of the chemical processes on a commercial scale to produce a sufficiently pure product.

Seaweeds as food for cattle and beasts have never achieved popularity, partly perhaps due to lack of advertising and partly on account of inadequate experiments to determine their food values. So far as the land is concerned there is no doubt that the brown algae are a good potassic and nitrogen manure, but so far no adequate method of dealing with their enormous wet bulk has been devised. Their use is therefore restricted to areas close to the region of supply. The spread of civilisation with its greater range of foods is slowly eliminating the use of seaweeds as human foods, even in such strongholds as Japan and Hawaii. One must therefore accept the fact that the present known types of edible algae will never again achieve a wide use.

The somewhat unhappy story related above should not, however, be a deterrent to future generations. If the difficulties can be overcome there is no reason why a flourishing industry should not arise. One may venture to prophesy that success is more likely to be achieved if more than one product is manufactured. Thus it should be possible to establish a successful industry based upon the production of alginic acid, manures and animal foods. If one product temporarily goes out of favour the others will help to tide over the depression. In the early stages of an industry it is probable that a wider range of products might avert a crisis until the industry has become established.

Summing up the present position it is doubtful whether an improvement can be made on de Launay's comment, even though it was written in 1902: "Mais, en industrie comme en science, les recommencements sont fréquents; plus d'une méthode ou d'une idée que l'on avait abandonées comme ayant fait leur temps, reparaissent un beau jour, un peu transformées, avec des airs de merveilleuse nouveauté." Another comment equally to the point was made by the author of the *Report on Home Industries in the Highlands and Islands*. This writer said: "No doubt the utilisation of marine algae will bring many problems, many of which will be economic, others chemical and mechanical, while some will be social, but with courage and foresight these should be capable of a satisfactory solution, to be attempted each in its turn as a particular question arises."

In preparing this volume I have been much aided by valuable criticism and advice from Dr. E. M. Delf; Prof. J. B. Speakman also very kindly allowed me to see the manuscript of two papers on alginic acid derivatives before publication. Considerable assistance in the preparation of the manuscript, index and figures has been afforded me by my wife and Mrs. B. O. Parks, and to both of them I am very grateful.

Auckland, New Zealand
1946

Delays caused by factors outside the author's and publishers' control have resulted in some time elapsing between the writing of the book and publication. The results of subsequent work have been incorporated as far as possible in the text or by addenda.

Auckland, New Zealand
1949

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CHAPTER I

OCCURRENCE AND DISTRIBUTION OF SEAWEEDS

AN introduction to any account of the economic uses of seaweeds must needs commence with a brief survey of the species involved, together with some information about their distribution in the world. Generally it is the freshly gathered plants that are of economic use, but there are some industries which utilise seaweeds that have been cast up on the shore by the tide. In this connection it is worth noting that in certain parts of the world vast quantities of such driftweed are to be found. The enormous amount of seaweed that exists in the world is probably not fully realised: if it were, it is possible that greater efforts would have been made in the past to find some means of utilising all this raw material. In certain parts of the coast of Great Britain, the seaweeds that grow on the rocks and just below low-water mark seem spectacular enough when seen in great quantity at low tide, but on the Pacific coast of North America, around the Falklands, on the west coast of South Africa and elsewhere, the size and abundance of the larger seaweeds assume far more majestic proportions* (Plates 1, 2, 3).

Classification. Seaweeds belong to the group of plants known as the Algae, which contain some of the most primitive members of the plant kingdom. It is known that the algae evolved very early in the geological history of the earth and evidence of their primitive nature is to be found in their structure. Present-day forms do not seem to have evolved further to any great extent, although in some cases they are more complex than the majority of the ancestral forms. Algal remains have been found in the very lowest fossil-bearing rocks, and whilst some of the plants that lived in those bygone ages were quite different from the ones living to-day, there were others that were very similar to living forms. The early development of species morphologically akin to living examples is particularly characteristic of the lime-encrusted red seaweeds, which appear to have changed but little.

* Fritsch 1943.

The algae differ from the higher plants in that they do not possess true roots, stems or leaves. However, some of the larger species, upon which the industries are primarily based, possess attachment organs or holdfasts that have the appearance of roots, and there may also be a stem-like portion called a stipe, which flattens out into a broad leaf-like portion or lamina (e.g. *Laminaria*, Fig. 4). Some species consist simply of a flat plate of tissue (e.g. *Ulva*), whilst in others the plant body, or thallus, is composed of a narrow, compressed or tubular axis with similar branches arising from it (e.g. *Gelidium*, Fig. 11*a*). The smaller species differ from those described above in that they are mainly filamentous.

A casual inspection of the seaweeds on the coast is sufficient to show that they are not all of the same colour. Colour, or rather the nature and proportions of the colouring pigments, plays a considerable part in the primary classification of the algae. Thus in the green seaweeds the green pigments are present in much the same proportions as they are in land plants, but in the brown algae they are masked by the presence of the brown pigment fucoxanthin, and in the red algae by the red pigment phycoerythrin. In the primary classification the algae are divided into the following four principal groups: the green algae or Chlorophyceae, the brown algae or Phaeophyceae, the red algae or Rhodophyceae and the blue-green algae or Myxophyceae.* The Chlorophyceae and Myxophyceae occur in the sea, in fresh water and on land, e.g. on tree trunks and in the soil. The Phaeophyceae and Rhodophyceae, on the other hand, are nearly all confined to the sea, though one or two species do grow in fresh-water streams. From the industrial viewpoint it is members of the Rhodophyceae and Phaeophyceae that are most important, partly because of the nature of the materials they contain, and partly because they occur in sufficient quantity to possess an economic value.

Reproduction. It has been mentioned that the algae differ from land plants in their structure, but they also differ in their mode of reproduction. Thus, flowering plants usually reproduce themselves by means of seeds, but algae secure perpetuation of the species by other methods. One of the commonest is by means of small, motile, single-celled bodies that are produced in vast quantity, either from unmodified cells or in special struc-

* There are a number of other groups, but these are composed of small plants which are not of economic importance.

tures. According to whether these are produced sexually or asexually they are called gametes or zoospores respectively. Motile gametes and zoospores are common units of reproduction in the green and brown algae, but the red algae are rather different. In the Rhodophyceae the asexual spores are non-motile and are formed in tetrads; hence they are known as tetraspores.* This group also possesses other types of non-motile spores, e.g. monospores and polyspores. A further characteristic feature of the red algae is the retention of the female gamete on the parent plant. This has resulted in the origin of a special parasitic generation which gives rise to a structure known as a carposporangium in which non-motile carpospores are produced.

It is obvious that a knowledge of the means of reproduction of algae is extremely important if they are to be cropped annually for economic purposes, otherwise mistakes might be made and whole areas denuded of the valuable species. In other cases, as in Japan where algae are actually cultivated (cf. p. 162), it is equally essential to know the full details of the life history and reproduction of the species. Apart from the special reproductive bodies, many of the seaweeds are also able to regenerate a new thallus from the cut stump or stipe. This property is obviously of considerable commercial advantage, and fortunately this power of regeneration is widely possessed by many of the larger brown seaweeds. Very often the rate and degree of regeneration depends on the place where the cut is made, e.g. if the plant is cut off too low down, regeneration may not occur or may be very slow. However, this is not the place to describe these features in full, and further details about the life-histories of the various algae that are of economic use can be found in any text-book on the algae;† for our immediate purpose it is more important to consider the places and conditions under which the different species grow.

Distribution: Europe. The most conspicuous algal denizens of fresh waters belong to the Chlorophyceae. A species such as *Enteromorpha intestinalis* may, at certain seasons of the year, become particularly abundant and form a floating green cover to quiet backwaters or lakes. Such green algae also usually occur

* Tetraspores are also found in one order of the brown algae.

† Fritsch, F. E., *Structure and Reproduction of the Algae*, Vols. 1 and 2 (Cambridge, 1935, 1945).
Smith, G. M., *Cryptogamic Botany*, Vol. 1 (McGraw Hill, 1938).
Tilden, J. E., *The Algae and Their Life Relations* (Univ. Minnes. Press, 1935).
Chapman, V. J., *Introduction to the Study of Algae* (Cambridge, 1942).
Oltmanns, F., *Morphologie und Biologie der Algen* (Jena, 1922).

in abundance in localities where there is a sewage outflow, because the water is rich in nutrient materials and this promotes luxuriant growth. The excessive development in 1910 of the green alga *Ulva lactuca* in Belfast Lough (Cotton, 1910) affords a good example of this phenomemon.

This predominance of green algae is not evident on the sea shore. A visit to the majority of the rocky coasts around Great Britain reveals the fact that usually the most conspicuous plants

FIG. 1. *Pelvetia Canaliculata* (× 6/7), (Kyles of Bute)

are different kinds of brown seaweed, though towards low-water mark there may be a moss-like carpet of red algae. This general statement would hold true also for most of the rocky shores on the Channel and Atlantic coasts of France, the north sea coasts of European countries, the coast of Iceland and the Atlantic and Pacific coasts of North America. Around the coasts of Europe it may be observed that each one of the principal kinds of brown seaweed, and also some of the Rhodophyceae, occupies much the same relative position on the shore.

This zonation is a well-established phenomenon, and the usual vertical arrangement in European waters is as follows: there is first a band of small bushy plants called *Pelvetia canaliculata* or

Fig. 2

Left: *Fucus vesiculosus*, portion of plant (× 1/5)

Centre: *Fucus spiralis* (× 0.4)

Right: *Ascophyllum nodosum*, portion of plant (× 1/5)

"channel wrack", which will always be found near high-water mark (Fig. 1); below this there will commonly be a larger species named *Fucus spiralis* (Fig. 2), or alternatively a closely allied form *F. platycarpus*.* Both of these have a broader branching system or thallus, with a well-marked stipe at the base arising from a disc-like hold-fast. Further down, and about the middle of the shore, two different brown algae are to be found; these are often collectively referred to as the bladder wracks because of the gas-filled vesicles they bear. The first, which often grows to quite considerable lengths, is known as *Ascophyllum nodosum* or "knobbed wrack" (Fig. 2). In the Orkneys this plant is called "yellow tang", because in the north it seems to be rather more olive-green in colour as compared with the other species. This difference in colour is less noticeable in southern England, but so far no biochemical investigation has been carried out in order to discover the cause of the difference. It has recently been found by David (1943) that this plant at Aberystwyth produces one bladder and the adjacent portion of thallus in a single year. If this observation is correct then the number of bladders on the main axis are a measure of the age of the plant. Since as many as nine or more bladders may be counted along a single length of thallus some of these plants are quite old. There is some evidence, however, which suggests that these observations are not valid for every locality.† The true bladder wrack, that occurs in a zone either above or below the *Ascophyllum* or else mixed with it, is known as *Fucus vesiculosus* (Fig. 2). This species is also known by the name of "lady wrack" or "black tang" in Scotland. The vesicles, as also those of *Ascophyllum*, are normally full of a gas, and so enable the plant to float near the surface when the tide comes in; in this way the plants receive more light for photosynthesis over a longer period of time.

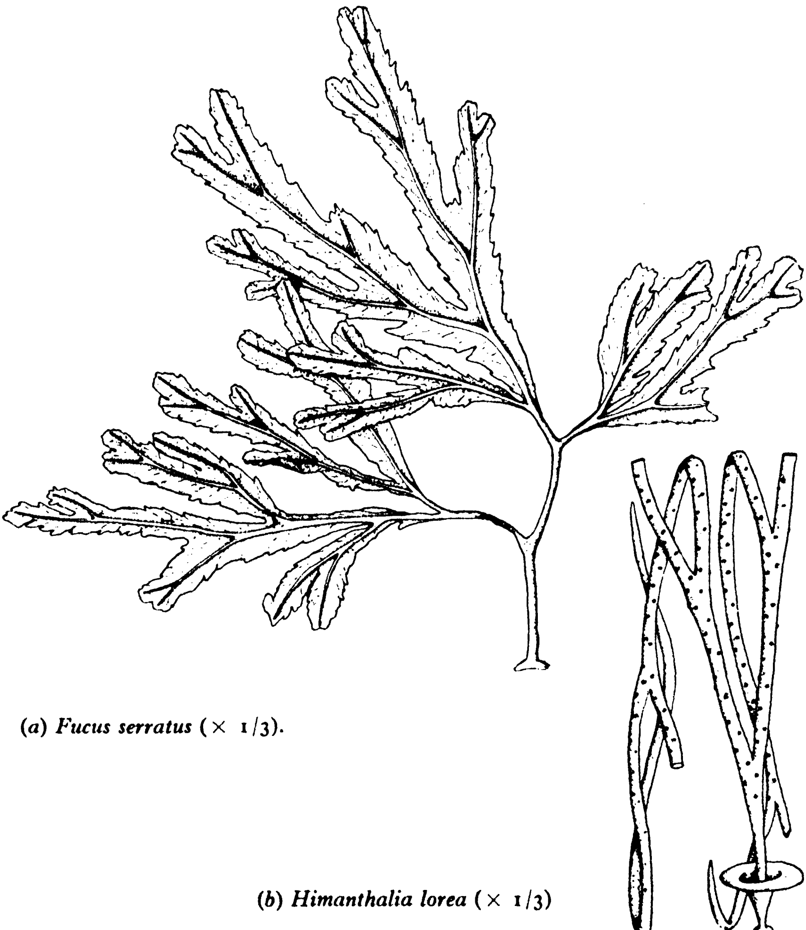
Near low water-mark there is another species, the "black" or "serrated wrack" (*Fucus serratus*), which does not have any vesicles (Fig. 3*a*). It is readily recognisable by the serrated edge of the thallus, whence it takes its name, and there is also the name of "prickly tang" given to it in the Orkneys. The above are the principal brown rockweeds which are exposed for some length of time during the majority of the inter-tidal periods.

At lower levels, where there is hardly any exposure, the nature

* Sometimes regarded as a variety of *F. spiralis*.

† Macfarlane (1932) found that two bladders are produced annually. The plant probably behaves differently in various localities and therefore any general deductions concerning annual increments would be premature.

of the vegetation changes. Thus, around low-tide mark of ordinary spring tides, the first of the big oarweeds is to be found. This has a basal attachment portion, then a stem-like stipe



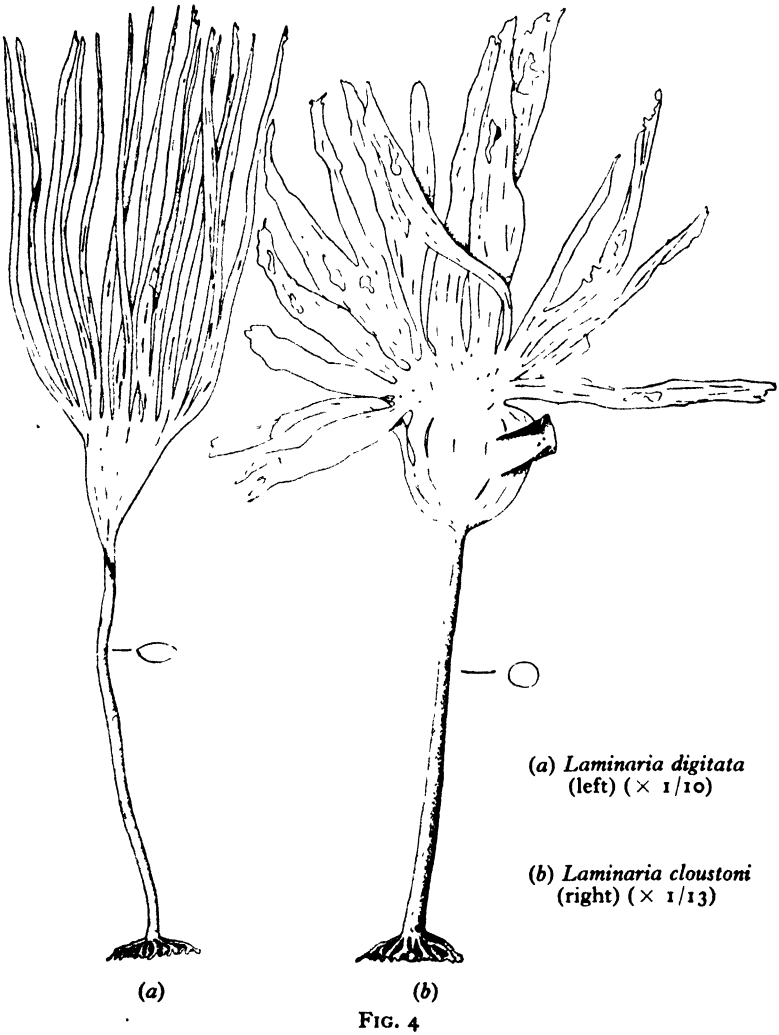
(*a*) *Fucus serratus* (× 1/3).

(*b*) *Himanthalia lorea* (× 1/3)

FIG. 3

which expands into a broad divided blade from which it derives its name of *Laminaria digitata* (Fig. 4*a*). Several varieties of this species have been recognised, in particular vars. *stenophylla* and *flexicaulis*, though in the literature these sometimes have been given specific rank. Commercial users of the alga do not usually trouble to distinguish these varieties but it may be important that they should, because analyses (cf. p. 70) show

that the varieties possibly differ from the parent species in their chemical composition. *L. digitata* is known locally around the country under various names, e.g. "red ware" in the Orkneys, "sea wand" in the Highlands, and "sea girdles" in England.



(*a*) *Laminaria digitata* (left) (× 1/10)

(*b*) *Laminaria cloustoni* (right) (× 1/13)

(*a*) (*b*)

FIG. 4

In many places where rocks are replaced by stones or shingle another type of oarweed is commonly found, though it can also grow alongside of *L. digitata*. This plant has a long blade about

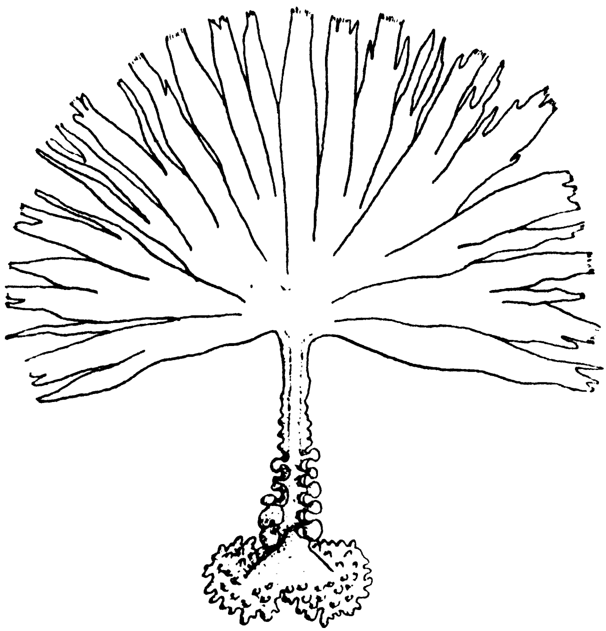
four to six inches wide with two rows of "bullosities" along its length. It is called *Laminaria saccharina* or "sugar wrack" because it is sweet to the taste, owing to the presence of a sugar alcohol (cf. p. 220). The former of these two oarweeds normally grows from low-water mark down to about two to three fathoms, where it is replaced by a related species, *Laminaria cloustoni** or "tangle", which normally lives between four and twenty fathoms (Fig. 4*b*). In Long Island Sound (U.S.A.), where there is a strong race, oarweeds are said to have been pulled up from 100 fathoms (600 feet), but this depth is exceptional.

Algae allied to the species described above are widely distributed in the colder waters of the earth, and they are particularly abundant in the North Atlantic, the Arctic Ocean and the North Pacific. They are not able to grow in warm waters, because they cannot reproduce themselves when the temperature of the sea is more than about 18° C. They do not grow higher up on the shore because they cannot tolerate exposure for any length of time: nearly all their life they must be covered with water. They will only occur at higher elevations if there are deep rock-pools in which they can grow submerged.

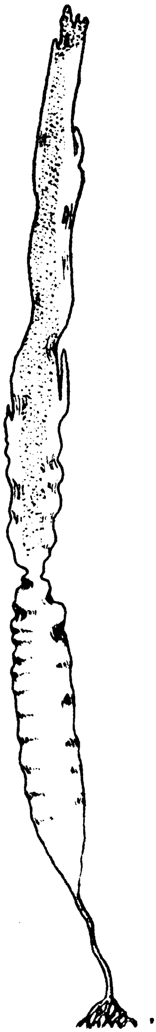
One may sometimes find, also growing in sandy or rocky places below low-water mark, two other members of the Laminariaceae. The first species possesses a swollen base and a flattened stipe with frills along the edge: this is known as *Saccorhiza bulbosa*. The second species has a broad, thin, leafy blade with a distinct mid-rib, whilst at the base of the main blade there will usually be a cluster of smaller and thicker elliptical leaflets, which bear the reproductive organs. This plant is *Alaria esculenta*, known as "murlins" in Ireland, "badderlocks," "bedderlocks" or "daberlocks" in Scotland, "mirkle", "honey-ware" or "henware" in the Orkneys, and "marinjarin" in Iceland. The name henware is simply a modification of honey-ware, i.e. sweetware. The word "ware" itself is probably identical with the word "wrack"; the corresponding Anglo-Saxon word was "war" or "waar", whilst dialect variations of the word are seen in "wore", "waur" and "ore" (cf. p. 36).

Apart from the principal brown algae a carpet of moss-like red seaweeds will often be found growing in the lower half of the zone exposed at low tide: the plants not only form an open carpet but they may also grow under the brown seaweeds. There are two or three different types of these algae which are often collectively known as Irish moss. In other parts of the

* Often called *L. hyperborea* in Continental literature.



(*b*) *Saccorhiza bulbosa* (× 1/3)



(*a*) *Laminaria saccharina* (After Oltmann's) (reduced)

FIG. 5

world similar red seaweeds are known as Ceylon moss and Chinese moss (cf. p. 90). The true Irish moss is *Chondrus crispus* (Fig. 6); another plant very like *Chondrus*, but with evidence of channelling and bearing papillae or short proliferations on the thallus, is known as *Gigartina stellata*. Towards high-water mark quite a different kind of red seaweed can frequently be found, especially in spring and summer. This is characterised by a very thin delicate thallus, purplish in colour,

FIG. 6. Two growth forms of Irish Moss (*Chondrus crispus*) (× 2/3)

which lies extended along the rocks when the tide is out. In England it is known as "laver", in Scotland as "slack" and in Ireland as "sloke", "slouk", "sloukaen" or "sloukaum". The scientific name is *Porphyra*, the common European species being *P. umbilicalis*.*

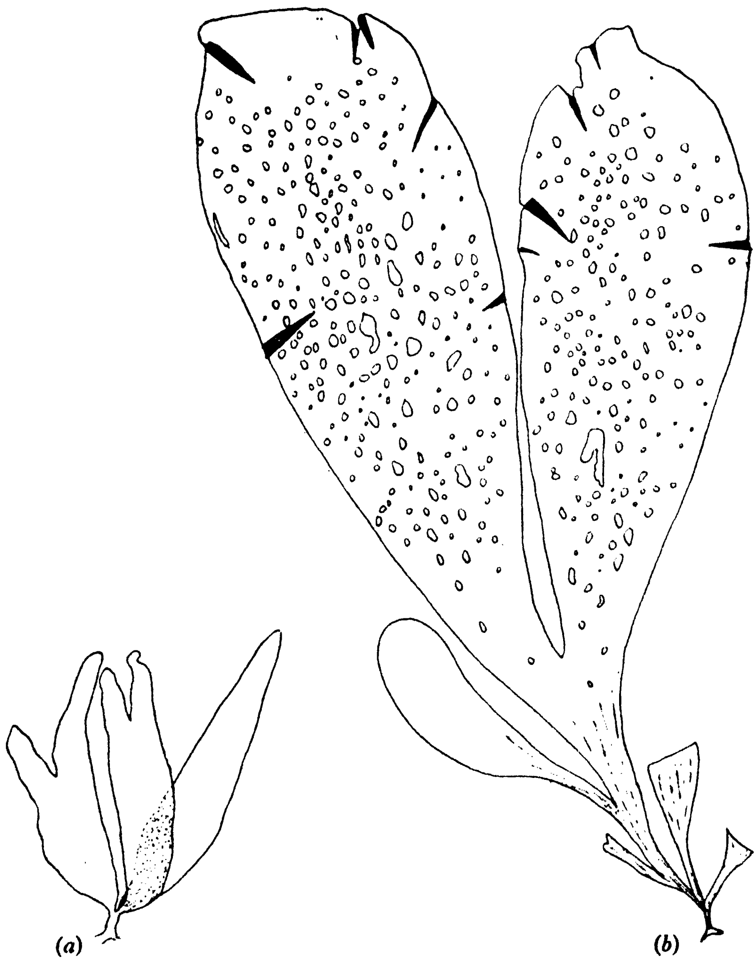


FIG. 7. (*a*) *Rhodymenia palmata* (× ½). (*b*) *Rhodymenia pertusa*, Anadulse (× ½) (After Okamura)

There is however yet another red alga which must be mentioned. This is commonly known as "dulse", whilst the Latin name is *Rhodymenia palmata* (Fig. 7): it grows on rocks near low-

* For references to other species of *Porphyra* cf. pp. 26, 162.

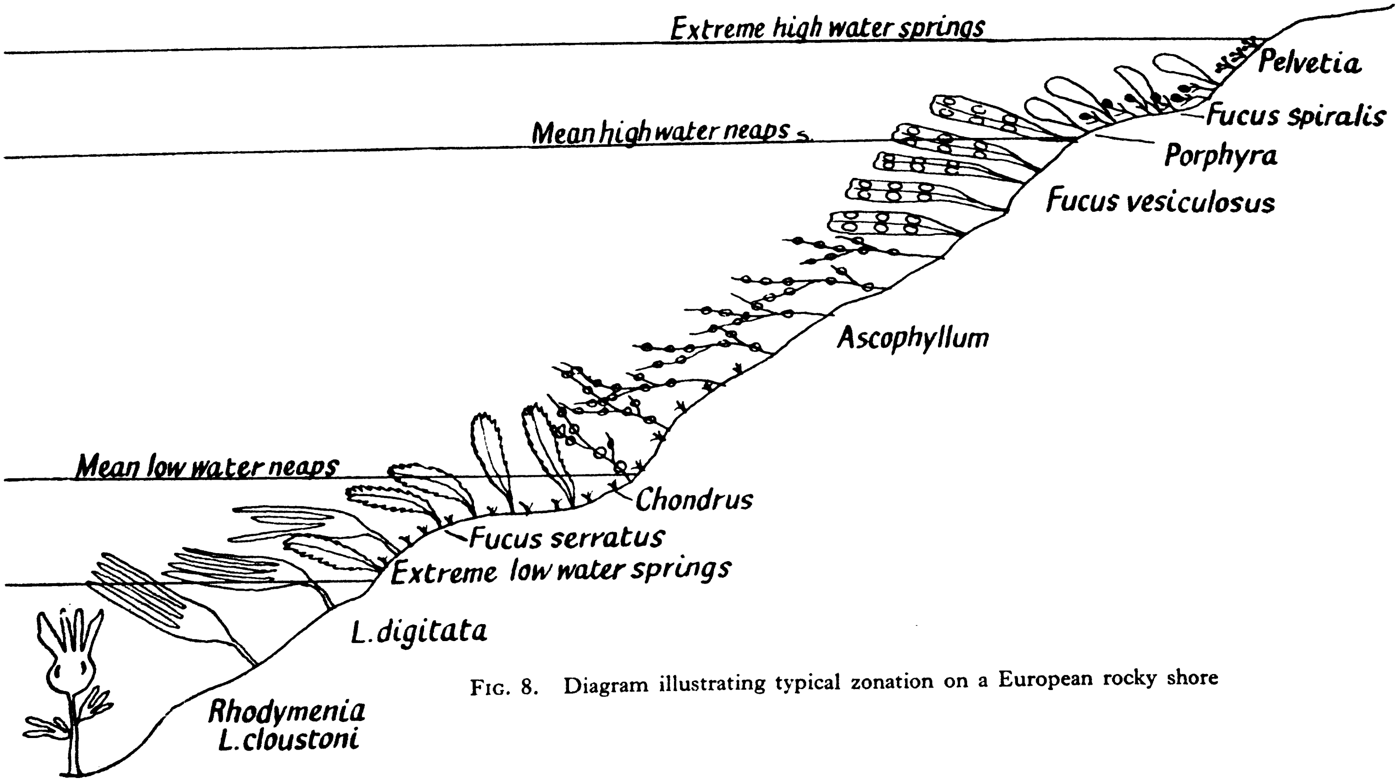


FIG. 8. Diagram illustrating typical zonation on a European rocky shore

water mark, but it is often found in abundance on the stems of *Laminaria cloustoni*. Considerable quantities of this species frequently occur in the drift cast up on the shore. Another name for *Rhodymenia* is "Neptune's girdle" because of its resemblance to a ribbon; in Norway and Lapland it is also known as "sea-devil" or "horse seaweed" because of its use in fodder (cf. p. 124).

This completes our account of the principal algal zonations to be found in European waters, and a diagrammatic representation of a common type of distribution is set out in Fig. 8. Comparable zonations, albeit with different algal species, can be found on the Pacific coast of North America, around the shores of South Africa, in New Zealand and elsewhere. Outside of Europe and North America, however, the brown rockweeds have not been used extensively for commercial purposes and hence these other zonations are not of such immediate interest.

Some of the local names for the seaweeds that grow on European shores have been mentioned in the description above. During a tour of the coast of Great Britain some years ago, an opportunity occurred to note down as many as possible of the local names by which members of the Laminariaceae were independently or collectively known. The result was extremely interesting, and the following list gives some idea of the great variety of names that may be found.

Liver weed Pennant weed } S. England Oarweed Pleace weed Weather glass Scarf weed Cowstail Kelpie (Caldy Island) Wheelbangs (Seahouses, Northumberland) Tang or Tangle* (Scotland—refers usually to stems only) Ware (Scotland—refers usually to leaf only) Flans Tangle tail (Whitburn) Pillie weed Slid Vares or Mhares = Gaelic version (Kintyre) May weed (refers to May cast only (cf. p. 58))	These names refer to oarweeds generally

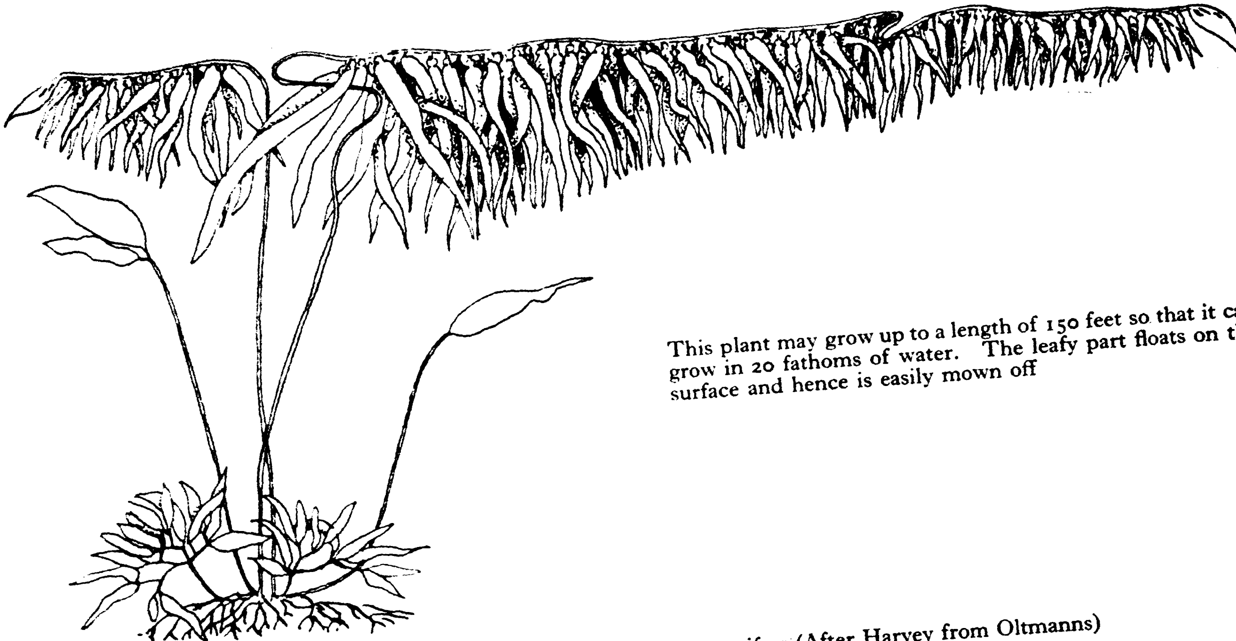
Bale or Baleware = oarweed cast as compared with buckleware for bladder-wrack cast.
Seakale (Loch Fyne)
Bruchd = *Laminaria* cast (Gaelic)

* Derived from the German "Tange", meaning Seaweed.

Leag (Kyleakin, Skye) = *L. cloustoni* cast
Sea girdles (England—refers to *L. digitata*)
Redware (Orkneys—refers to *L. digitata*)
Sea warld (Highlands—refers to *L. digitata*)
Braggair = *L. digitata* (Hebrides)
Liadhaig = *L. digitata* (Gaelic)
Dabbylocks (Buckie) apparently refers to *L. saccharina*, though one would have expected it to be *Alaria*
Redtop or Bardarrig = *L. digitata* var. *stenophylla*
Langetiff = *L. saccharina* (Gaelic)
Swarts = *L. cloustoni*

Distribution: America. The seaweeds of Europe and the Atlantic coast of North America are not the only ones which are, or can be, used commercially. On the Pacific coast of America there are a number of very large brown algae, closely allied to the British oarweeds, which have at different times assumed considerable importance. These seaweeds, which are generally known as kelps, are veritable giants of the deep as compared with the British species, and when they grow together in quantity they form a real submarine forest (Fritsch, 1943). Divers engaged on salvage work in the midst of a thick *Laminaria* bed off the Orkneys have reported that it was like working in a dense thicket, but as several of the Pacific brown seaweeds are more than one hundred feet long, a walk in a thick bed would be like penetrating a tropical forest.

One of the largest of these brown algae is known as *Macrocystis* or in local parlance, as "long bladder kelp", "brown kelp" or "great kelp" (Fig. 9). It may grow up to 195 feet long, but reports by earlier explorers (e.g. Bory de St. Vincent) of plants 700–1,500 feet long have now been discounted. It appears to have a life of about five years, and single plants may weigh as much as 92 lb. and have a holdfast three feet in diameter. Plants have been recorded weighing as much as 300 lb., but this is almost certainly an exaggeration. There is a long branching stalk, which arises from a ramifying basal attachment system, and the upper ends of the branches bear rows of leafy laminae, each of which has a small swollen bladder at its base. By means of these bladders, which are gas-filled, the fronds are kept floating at the surface of the sea. In view of their great size these seaweeds can have their rooting portion down at depths of 10–15 fathoms, though they achieve their best growth in depths of about 8 fathoms (48 feet). It has recently been found (Smith, 1942) that the two species of this genus that grow



This plant may grow up to a length of 150 feet so that it can grow in 20 fathoms of water. The leafy part floats on the surface and hence is easily mown off

FIG. 9. The big kelp of California, *Macrocystis pyrifera* (After Harvey from Oltmanns)

on the Pacific coast occupy different ecological positions. *Macrocystis pyrifera*, which is the larger of the two, grows in beds some distance off-shore, whereas nearer inshore one finds the other species, *M. integrifolia*.

Often growing with *Macrocystis* is another giant alga, *Nereocystis luetkeana*, which is commonly known as "bull kelp", "bladder kelp", "black kelp" or "sea otter's cabbage" (Plate 1). This seaweed also grows in deep waters, at depths of 15–75 feet, where a single plant may reach a length of 120 feet. The tough, whip-like stalk arises from a holdfast, which may be as much as one foot in diameter, and terminates in a large, swollen, hollow bulb, seven to eight inches in diameter, and with walls one inch thick (Plate 2*b*). This bladder bears long, leafy outgrowths which serve not only as the assimilatory organs of the plant but also as the organs on which the reproductive bodies are produced. As this plant appears to be an annual, the rate of growth must be considerable, especially in view of the length it may attain. Specimens have been measured with a leaf area of 754 square feet, whilst the average weight of a single plant is about 18 lb., with a maximum of 56 lb. in the autumn when fully mature.

Another species very similar to the bull kelp, though somewhat larger, is the "elk kelp" or *Pelagophycus* (Plate 2*a*). Individual plants of this species frequently attain 120 feet in length and weigh from 16 to 71 lb. This species, which has a restricted distribution, does not grow in great abundance, and occurs as single plants or in small patches associated with beds of *Macrocystis*. Yet another Pacific coast seaweed that is of importance, though neither so large nor so heavy, is *Alaria fistulosa*, or the "stringy kelp". This possesses a large, leafy blade with a hollow midrib down the centre with septa at intervals so that the blade floats in the water. At the base there are a number of short, thick, lateral blades which bear the reproductive organs. These are known as sporophylls and there may be as many as 220 of them on a single plant. Individual plants attain an average length of about 40 feet, but they weigh only about 6½ lb. (Plate 3). This species is closely allied to the European *Alaria esculenta* (badderlocks).

Of these Pacific giants, *Macrocystis pyrifera* has a wide distribution, and in the north extends from Lower California up to Alaska, its southern limit being set approximately by the 20°C. water isotherm of the warmest month. The second species of the genus is distributed over a smaller area, Vancouver Island

to Central California (Smith, 1944). The genus is unable to spread into warmer waters because at temperatures higher than 18°–20°C. it does not form any reproductive bodies. It therefore provides an excellent example of a geographical limit

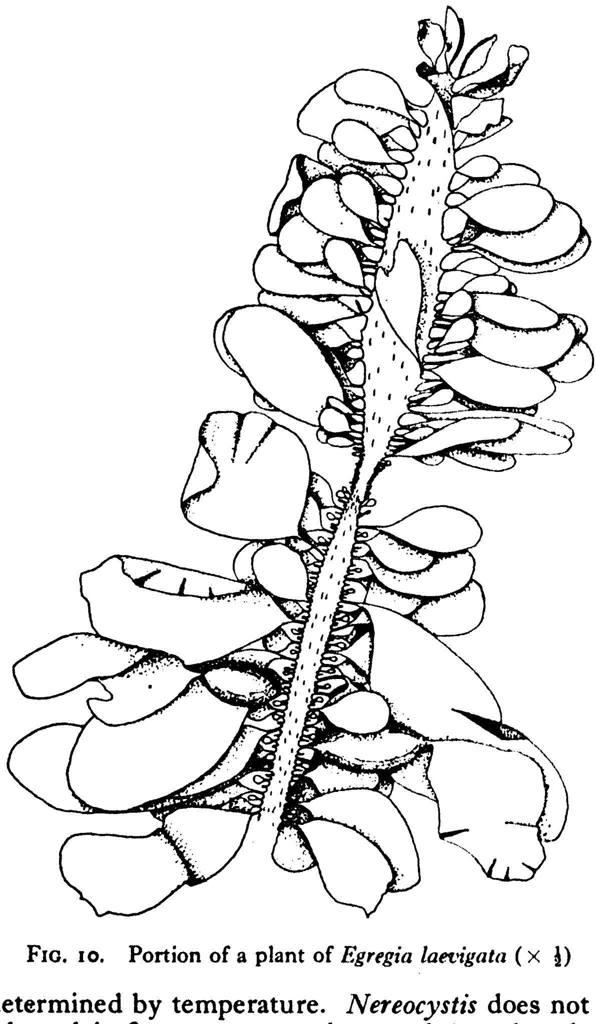


FIG. 10. Portion of a plant of *Egregia laevigata* (× ½)

being determined by temperature. *Nereocystis* does not grow so far south and is first encountered around Los Angeles, but it spreads farther north in Alaska. *Pelagophycus*, on the other hand, is a restricted southern form, and grows only on the coasts of Southern and Lower California. *Alaria fistulosa* is even more

northerly than *Nereocystis*, and is principally confined to Alaska and British Columbia.

The rocky shores of the Pacific coast of North America, Canada and Alaska are usually densely covered with a rich algal vegetation. In the upper part of the shore there are a number of species of *Fucus*, but at present they have no commercial importance. A plant that could form an important raw material is the "feather-boa kelp", "ribbon kelp" or *Egregia* (Fig. 10). This genus, which consists of two species, belongs to the Laminariaceae and, unlike the other members, is able to tolerate some degree of exposure. The plants grow on the shore in the rock pools near low-water mark, and one species, *E. menziesii*, frequently forms a continuous belt (Smith, 1944). There are also a number of species of *Laminaria* and other oarweeds belonging to genera such as *Thalassiophyllum*, *Cymathere* and *Costaria*. These, however, are not likely to assume any commercial importance so long as extensive beds of the larger kelps remain to be exploited.

In addition to the large members of the Phaeophyceae there are several species of the red algal genus *Gelidium*. These are larger than their British allies, and occur in sufficient abundance to be of commercial use in the preparation of agar (cf. p. 101). As the red algae are generally more delicate than the Phaeophyceae, they grow near low-water mark, or in rock pools, where they will not be subjected to such long periods of exposure. Often search must be made for them underneath the heavy covering of brown algae that festoons the rocks.

Distribution: Hawaii. Leaving behind the Pacific coast of North America we carry on westwards until Hawaii is reached. Here dense growths of red and green seaweeds can be observed growing in the pools amidst the delicately coloured corals, or else forming a close carpet in the lagoons. A very large number of these seaweeds have been used for hundreds of years, and indeed still are used, as important articles of food. The majority are small, and there are no spectacular species comparable in stature to the Pacific kelps. Because of their small size they are principally collected by hand and have to be picked out from other, useless forms. By far the greater quantity of species used are red seaweeds, but a certain number of green and brown ones are also collected.

The zonation of the littoral seaweeds, that is such a characteristic feature of the temperate seas, is not so obvious in these

warmer waters. The different algae tend to occur mixed together and not in more or less pure stands, and the majority are to be found in the rock pools or in the sublittoral. The number of algae that can grow on the beach, where they are exposed to the hot tropical sun, are few in number as compared to those that grow perpetually submerged. The amount of water that beach algae would lose during the time of low tide in the hotter parts of the world makes the shore a very unsuitable place for the growth of such relatively delicate plants.

Distribution: Japan. Leaving Hawaii and proceeding farther across the Pacific to Japan one finds that many of the red seaweeds that are to be found growing around low-water mark, in tidal pools or in the shallow sublittoral, are of commercial importance. The Japanese make extensive use of one species of *Porphyra* (similar to the laver in England), and so much is required that the seaweed is actually cultivated (cf. p. 163). Then there is the agar industry, which is concerned largely with species of the genus *Gelidium*, especially *G. amansii* (Fig. 11*a*), whilst another industry makes use of the red alga *Gloiopeltis furcata* (cf. p. 203).

Kelps also grow in the waters around Japan because the sea is not too warm, and a large number of species are known. The plants, however, do not reach the size of the American *Macrocystis* and *Nereocystis* and they are more like the European oarweeds. The north Pacific indeed seems to have been the home of the kelps, eighty different species alone being found in north-west America, and only slightly fewer in north-east Asia. The Japanese employ these algae in considerable quantity, and several important industries are associated with them. The Japanese kelps all grow in the deeper waters off-shore where they form very extensive beds. No account of the distribution of these beds appears to have been published, and information about the ecology of the different species is meagre. Japanese waters would undoubtedly merit an ecological investigation into the distribution of the Laminariaceae.

The principal species involved are *Ecklonia cava*, *Eisenia bicyclis* (Fig. 38), *Laminaria* spp. and *Undaria pinnatifida* (Fig. 37). In the adult *Ecklonia* there is a central leafy portion bearing numerous lateral leaflets or pinnae: in one species, *E. maxima*, however, the central frond is much reduced in relation to the laterals. Young plants, on the other hand, have very much the appearance of a *Laminaria* until they develop the lateral pinnae.

FIG. 11*a*. *Gelidium amansii* (*tengusa*) (After Okamura)

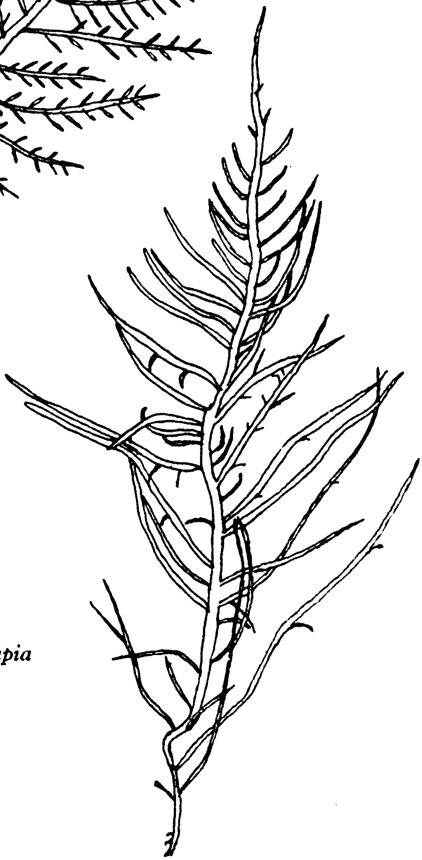


FIG. 11*b*. *Grateloupia filicina* (× 1)

Eisenia possesses what appears to be a branched stipe, but this is morphologically part of the primary lamina: a number of leafy blades arise from the apices of the two "branches". In *Undaria* the stipe continues up through the lamina as a prominent mid-rib just as in *Alaria*. The sporophyll, or spore-bearing portion, in

this genus is a dilated, undulating wing that is formed on both sides of the stipe just below the base of the lamina.

Distribution: Indonesia. Farther south in the Malayan Archipelago there is much use of the smaller red seaweeds, which grow totally submerged, but, as in Hawaii, there are no kelps that can be employed. A number of species are gathered, some of the commoner ones belonging to the Rhodophycean genera *Eucheuma* and *Gracilaria* (cf. p. 90).

Distribution: General. The general picture so far obtained should envisage the shores of Europe and eastern North America covered with brown seaweeds that form definite belts along the shore. Growing underneath the brown seaweeds, towards low-water mark, will be smaller red algae, whilst near high-water mark there may be a zone of laver: then in the sea itself are beds of oarweeds, their extent depending not only on how steeply the sea bottom slopes downward but whether it is suitable for the growth of the weeds; e.g. whether there is sufficient water movement and not too much silt deposition. A very similar picture could be drawn for the Pacific coast of America, except that, as might be expected, the various Phaeophyceae are different and are larger. It is said to be a Californian boast that everything in their State is bigger and better than elsewhere, and it must be admitted that this claim is fully justified in the case of the Phaeophyceae! In the warm waters of the world there is an almost complete lack of oarweeds and of the brown seaweeds that form distinct zones on the shore. The shores, in fact, are relatively bare of growth, and where algae do occur they are usually moss-like in appearance. In such places the best growth of seaweed, much of it composed of red species, is found in the coralline rock pools and beneath low-water mark.

Effect of War. The above is a very brief account of the principal areas in the world where seaweeds have been extensively used in the past. The 1939–45 war, in the same manner as the 1914–18 war, brought somewhat forcibly to our notice the fact that certain substances are in very great demand, even though only small quantities may be required; in war-time control of the sources may be lost, or in peace-time they may have been produced almost wholly from an enemy country. In the case of essential products the thoughts of man naturally turn to alternative sources, and the vast quantities of seaweeds to be seen on the shores suggest themselves as a potential source of at least

some substitute materials. That the British Empire is particularly interested in this aspect can be seen from the articles that have appeared recently by Moore (1941), Delf (1943 and 1944) and Chapman (1946), though contributions have not been lacking from other countries, e.g. Tseng (1944, 1945).

New Zealand. Apart from the countries that have already been mentioned, New Zealand has displayed considerable activity in considering the possibilities of her seaweed resources. Thus, as early as 1941, a bulletin on the subject (Moore) was issued by the Department of Scientific and Industrial Research.

The giant kelp *Macrocystis pyrifera* grows in the waters around New Zealand in sufficient quantity to be of economic value, and the major beds have recently been mapped (Rapson *et al.*, 1943). There are other brown oarweeds, belonging to the genus *Ecklonia*, which grow just below low-water mark, and these too might usefully be employed. The shore itself bears a vegetation arranged in belts or zones just as in England, but of course the species are quite different and their appearance is not the same. Near high-water mark there is a laver, *Porphyra columbina*, whilst near low-water mark occur various species of red algae that can be used for agar production (cf. p. 114). Also near low-water mark on exposed coasts, one may find a zone occupied by a remarkable brown alga: although this is related to the northern hemisphere genus *Fucus* it has the appearance of a *Laminaria*, but its fronds are divided by septa into numerous gas-filled compartments. This brown seaweed is known as "bull kelp" or *Durvillea*, being named after D'Urville, a French explorer

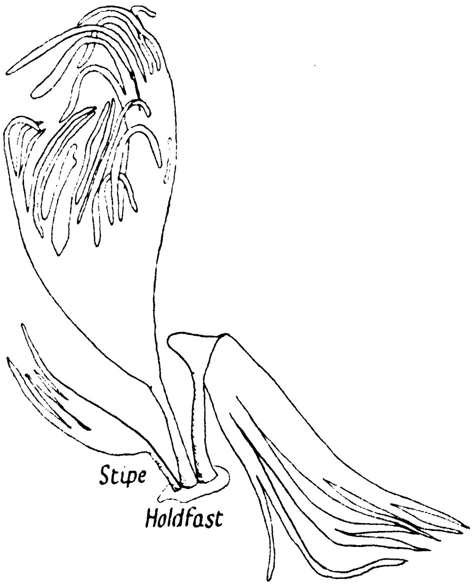


FIG. 12. *Durvillea antarctica* (× 1/38) (After Haricot)

(Fig. 12). The plant is a perennial, and is only removed by wave assault after the holdfast has been weakened by age and the innumerable burrows of boring animals. The common species is *D. antarctica*, but some of the plants of the related species, *D. harveyi*, are enormous, 30–40 feet long, with a frond area of 216 square feet, a stipe 8½ inches in diameter, and they may weigh as much as one hundredweight. New Zealand therefore has considerable natural resources which could be utilised.

Australia. Australia has also become interested in her seaweed supplies but, although the giant *Macrocystis* grows along the shores of eastern and southern Australia, at present the immediate object is the utilisation of certain red seaweeds, especially *Gracilaria confervoides*, that grow near low-water mark or down to several fathoms (cf. p. 112). It is hoped to harvest the *Gracilaria* in considerable quantities for agar manufacture, and a special dredge has been devised for the purpose.

South America. On the opposite side of the Pacific, the South American states possess beds of *Macrocystis* widely distributed down the coast from Peru to the Straits of Magellan. There is very little information, however, about the extent of these beds, or whether the alga is present in sufficient quantity to be of economic importance.* The important brown rockweeds, *Durvillea antarctica* and *D. harveyi*, occur near low-water mark in sufficient abundance to form well-marked zones. Red seaweeds, which no doubt could be used in the same way as in other parts of the world, grow on these shores and below low-water mark. *Porphyra umbilicalis*, for example, occupies a zone at the mid-littoral, whilst there are two species of *Rhodymenia* that form deep-water communities. Whether these countries will ever utilise their seaweed resources on a commercial scale cannot be foretold at present. Many peace-time products can be made from seaweed, and as the principal expense is usually in the collecting of the algae, the South American countries with their cheap labour might be able to build up a prosperous industry.

In the Falklands, and along the shores of Chile and around Cape Horn, always growing far beyond low-water mark, there are other giants of the deep in addition to *Macrocystis*. Some of these belong to the genus *Lessonia*, so named after the French

* The latest information is contained in an account by C. Skottsberg, in *Kungl. Svens. Vetens Handl.* **19**. 1941. No. 4.

scientist Lesson (Fig. 13). It is probably impossible to find a better description of these plants than that of Sir Joseph Hooker's in his *Botany of the Antarctic Voyage of 1839–1843*.

Describing the different species of *Lessonia* he says that they are "truly wonderful Algae, whether seen in the water or on the beach: for they are arborescent [tree-like] branched trees, with the branches pendulous and again divided into sprays from which hang leaves 1–3 feet long. The trunks usually are about 5–10 feet long, as thick as the human thigh . . . . The individual plants are attached in groups or solitary, but gregarious, like the pine or oak, extending over a considerable surface, so as to form a miniature forest which is entirely submerged during high tide or even half-tide, but whose topmost branches project above the surface at ebb. To sail in a boat over these groves on a calm day affords the naturalist a delightful recreation; for he may there witness, in the antarctic regions, and below the surface of the ocean, as busy a scene as is presented by the coral reefs of the tropics. . . . But it is on the sunken rocks of the outer coasts that this genus chiefly prevails, and from thence thousands of these trees are flung ashore by the waves, and with the *Macrocystis* and *Durvillea*, form along the beach continued masses of vegetable rejectamenta, miles in extent, some yards broad, and three feet in depth; the upper edge of this belt of putrefying matter is well inshore, whilst the outer or seaward edge dips into the water, and receives the accumulating wreck from the submarine forests throughout its whole length. Amongst these masses the best algae of the Falklands are to be found, though if the weather be mild, the stench, which resembles putrid cabbage, is so strong as to be almost insufferable. The ignorant observer at once takes the trunks of *Lessonia* thus

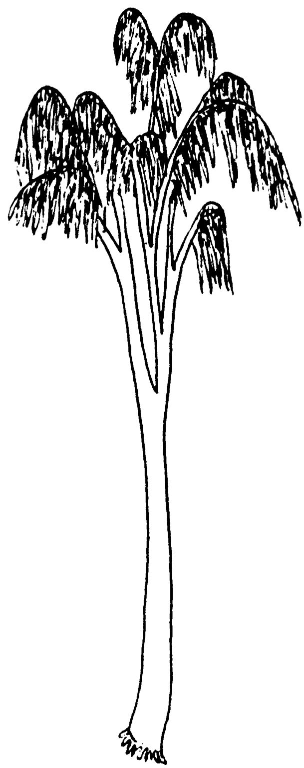


FIG. 13. *Lessonia fuscescens* (After Hooker)

washed up for pieces of driftwood, and on one occasion, no persuasion could prevent the Captain of a brig from employing his boat and boat's crew, during two bitterly cold days, in collecting this incombustible weed for fuel!"

South Africa. Another country which at present is making some use of her seaweeds is South Africa. The species primarily employed are the red algae, which grow from mid-tide to below low-tide mark, species of *Gelidium*, *Hypnea*, *Gracilaria* and *Suhria*.* A species of laver, *Porphyra capensis*, occurs in quantity on the west coast, but so far no use has been found for it. South Africa, however, has far greater potentialities because there are fairly extensive beds of *Macrocystis* on the west coast just north of Cape Town. The big bed of this weed, 130 miles long, reported by Sir Joseph Hooker on the Agulhas bank off the Cape of Good Hope has never been seen again, and there must have been a mistake about it. From the purely scientific point of view the world distribution of *Macrocystis* is intensely interesting. It will have been noted that there is a break in the distribution between Peru and Lower California. At the time when the species was spreading, the waters between Peru and Lower California must have been colder (below 20°C.), or else no spread could have occurred, because the species would not have been able to propagate itself. This fact is of importance in considering polar movements in past geological periods and also changes in world temperature distribution. The wide gaps in the distribution of *Macrocystis* between Australia, South Africa and South America could be accounted for by invoking some such hypothesis as that of Wegener's continental drift. According to this theory all these three lands were at one time part of a single great land mass and they have since drifted apart. The past and present distribution of some land and marine plants can be used to provide vital evidence for this theory.†

Associated with the *Macrocystis* in South Africa is an oarweed belonging to the genus *Laminaria* (*L. pallida*), and also the "sea bamboo" or *Ecklonia maxima* (*E. buccinalis*). Both these latter occur in some quantity and could be harvested; the *Ecklonia* reaches a considerable size because plants of nearly 33 feet long

* An account of the distribution and zonation of these algae can be found in the series of papers by Stephenson and his co-workers in the *Annals of the S. African Museum*, 1938–41.

† The present author is in favour of continental drift as the most satisfying explanation, but other theories can be advanced. This, however, is not the place in which to discuss them.

have been measured. Fig. 14 gives some idea of the relative size relations of these plants. At the end of the 1914–18 war Britten suggested that *Ecklonia* could be used for potash and he urged that a survey of its distribution should be made, but no action was ever taken. The South African oarweeds generally form

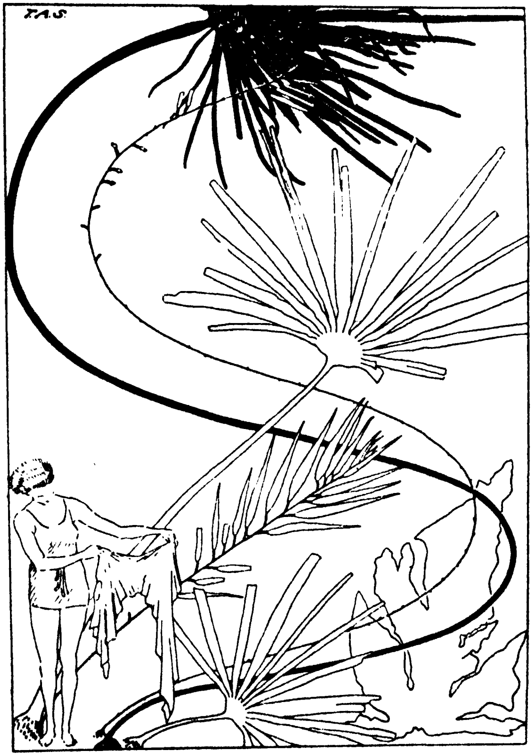


FIG. 14. Diagram to show size of *Macrocystis pyrifera* and *Ecklonia maxima* in South Africa. The black figure represents a large plant of the latter species and following the line of its stipe is an almost leafless plant of *Macrocystis*. The white fan-shaped figure is a small plant of *Ecklonia*. There is also a young plant of *Macrocystis* (After Stephenson) (see also Plate 20).

beds, 100 yards or more wide, fringing the shore from low-water mark, and are commonly more abundant and extensive in sheltered bays than on exposed coasts. *Laminaria pallida* dominates in the colder waters and *Ecklonia* in the warmer. *Macrocystis* in South Africa is a subordinate genus, and is usually found growing on the shore side of a belt of *Ecklonia* which serves to protect it, presumably from the full force of the sea. It is somewhat difficult to understand this distribution because on the Pacific coast of America the same species of *Macrocystis* is quite capable of combating heavy wave action.

The seaweeds of the world may be regarded as forming three great zones so far as their usefulness is concerned. There is the

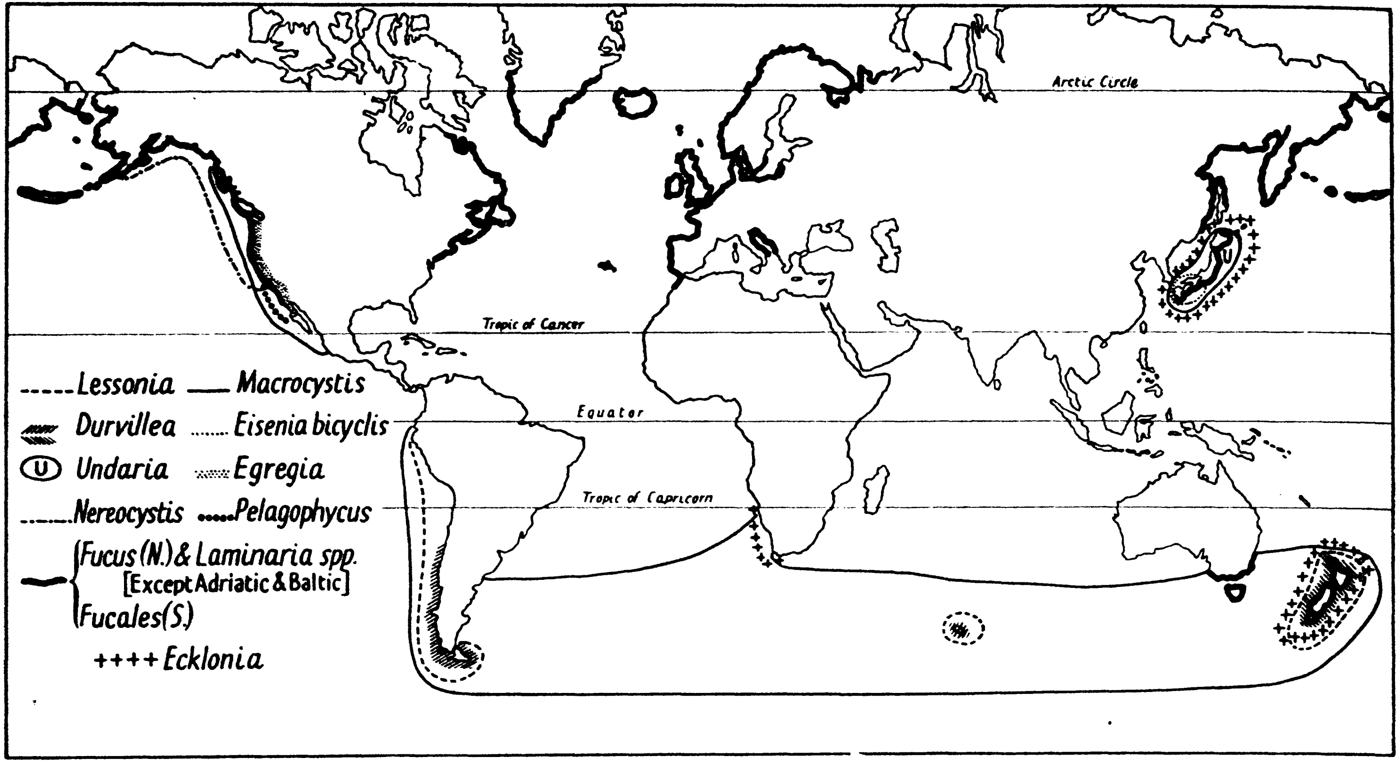


FIG. 15. Distribution map of some of the more important seaweeds used in industry or as food

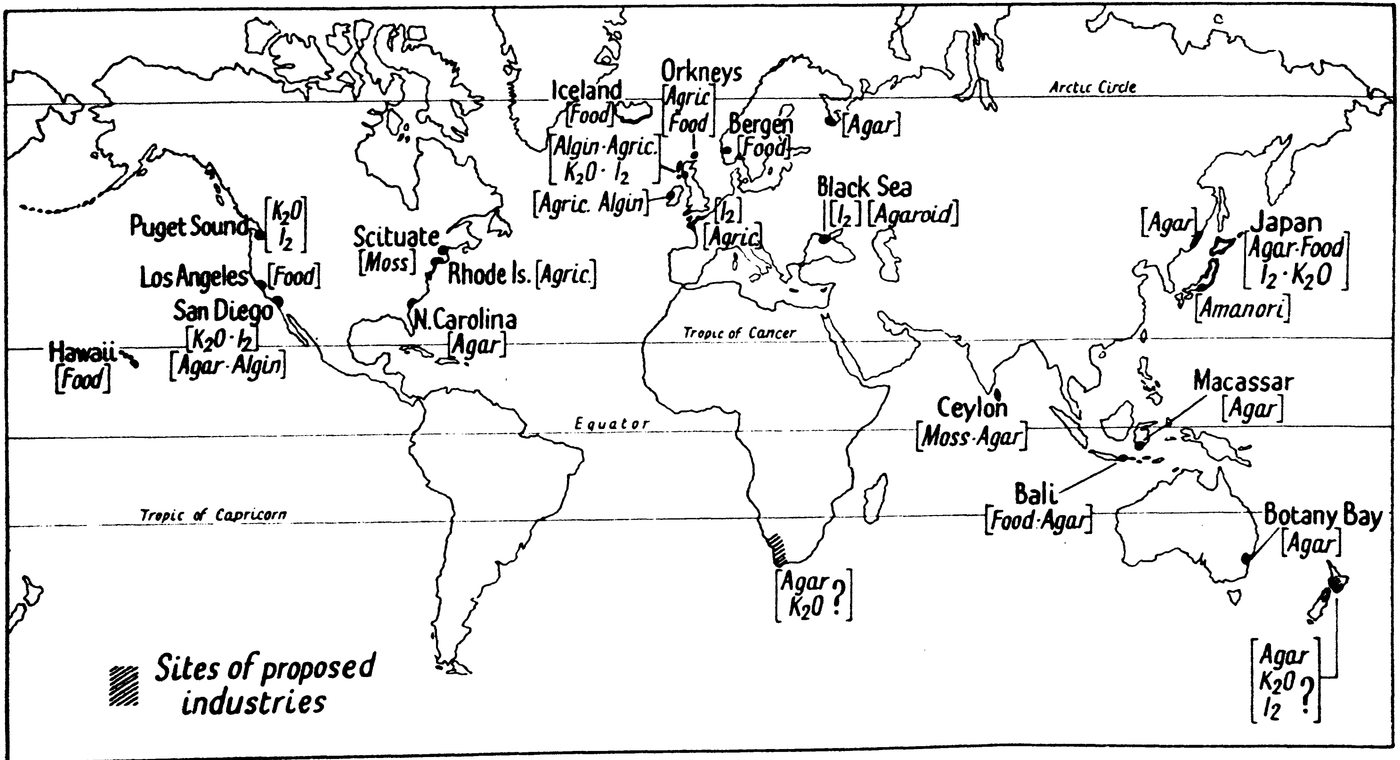


FIG. 16. Map showing the location of the main centres for the utilisation of seaweeds

north temperate and cold-water zone, in which large brown seaweeds occur in great quantity, though one can also find small quantities of useful red seaweeds. There is the central warm-water zone in which the principal valuable seaweeds belong to the Rhodophyceae, and then there is the south temperate and cold-water zone where again big areas of brown seaweed are to be found, though there are also quite considerable quantities of red algae. In Fig. 16 the distribution of the major algal industries has been set out in relation to the occurrence of the principal species involved, and this map should be compared with the seaweed distribution map of Fig. 15.

Fresh-water Algae. So far only seaweeds have been considered, but it has already been stated that there are algae that grow in fresh water or in the soil. It may be asked whether they do not have some use, and the answer to that question is that commercially it is only the seaweeds that really have any considerable value. There is a small green filamentous alga (*Chaetomorpha sp.*) that grows in sufficient quantity in Jamaica so that it can be collected and dried to a soft green cotton-like state, when it is known as "pelt". In this condition it forms a very useful packing material. An occasion has also been recorded when the Mississippi overflowed its banks in Louisiana, and when the waters receded they left behind a mass of green algal filaments which were so interwoven and compressed that they formed a natural paper. Moreland (1924), who went to investigate this phenomenon, was able to take some of the natural paper and actually type on it. This, however, was a very unusual occurrence and it is mentioned only because of its unique character.

In a rather different direction it has been suggested (Polunin, 1942) that fresh-water algae could be employed as manure for the land, whilst it has also been mooted that they could, in time of need, be used to augment ordinary foods for man. It has been recorded that as much as 90 tons of algal plankton have been removed daily from reservoirs, and it is argued that this could go direct on the land, as a form of green manure. It is very doubtful, however, whether any appreciable quantity could be produced as compared with the total amount of fertiliser required. Also the algal plankton is partly seasonal in its occurrence, and it might prove very difficult to produce large quantities at other times of the year. The fact that 110 tons of the diatom *Fragilaria crotonensis* was estimated (Gardiner, 1939) to

occur in a reservoir at the period of spring maximum is no very good argument for equal production at other seasons. So far as augmenting human food is concerned the references have mainly been to the animal constituents of the plankton.

Yet another example is the part played by certain blue-green algae in the cultivation of rice. In the early stages of its growth rice has to be flooded, and it also requires a considerable quantity of nitrogen in the soil. Under certain conditions rice is able to grow in the same field year after year without any manuring, and it has been shown by De (1940) that this is almost entirely due to the remarkable power possessed by certain blue-green algae of being able to abstract nitrogen from the air, and convert it into a form in which it can be used by the rice plant. The fixation of the nitrogen, as this process is called, is usually more efficient if bacteria are also present, and it is thought that the bacteria carry out the actual fixation whilst the algae, by their metabolic activities, maintain the surroundings in the most suitable state for the proper functioning of the bacteria. In the case of the rice fields the blue-green algae also play a part in aeration. This is because they produce oxygen during the process of food manufacture, and this oxygen can be used by the rice plants. Unless the algae are present during the period when the fields are flooded the aeration deteriorates, and the rice then becomes much more susceptible to disease.

Both marine and fresh-water algae are used by certain aquatic animals as food. The green fat of the turtle and the green material in the lobster betray the source of their food, although the green colour does not imply that they have eaten only green seaweeds; both the red and brown seaweeds contain the green colouring matter (chlorophyll) of plants, but in their case it is masked by the presence of other pigments. During the process of digestion in the stomach of an animal it is not unlikely that the green chlorophyll undergoes a different treatment to that accorded the coloured pigments, and as a result it becomes deposited in the tissues of the animal.

In the stomach of a fish called the gizzard shad, as many as 150 varieties of algae have been identified, whilst in that of another fish, the fat-head minnow, 128 species were recorded, so that these two at least are catholic in their tastes! In the Philippines the fry of the milk fish are fed on an algal "soup" called "lab-lab", which develops naturally in artificially constructed ponds. On the other hand many algae pass through the stomachs of fish quite undigested. It must be evident, therefore,

that in certain countries the fish may play a big part in determining the composition of the algal flora.

The importance of marine algae, and in particular the phytoplankton, as the food of fish has long been recognised, but it is only recently that attempts have been made, by "manuring" the sea, to increase the amount of phytoplankton available. It was believed (and subsequent experiments showed this belief to be correct) that if an enclosed body of water was treated with certain nutrient salts the quantity of the phytoplankton would increase, and that then the body of water would support a larger fish population (cf. p. 149). This has been amply proved by work carried out recently in Loch Sween in Scotland.

Another example of the dependence of fish upon algae has been recorded by Meier (1935) from the Weequahic reservation in New Jersey. Here the surface of one of the lakes was observed to be covered with algae, mostly Myxophyceae, and all the fish died within a few days. So far as could be ascertained the cause of death was suffocation due to lack of sufficient oxygen in the water. At the time there was a high temperature and a complete absence of any wind. The algal vegetation had increased to such an extent that all the dissolved carbon dioxide in the water was thought to have been used up and very little was diffusing in from the atmosphere. When all the carbon dioxide in the water was used up, the algae were unable to produce any more oxygen and so the fish died. The bulk of the algae were also Myxophyceae, and these are less powerful oxygenators than members of the other groups. Whilst this theory of suffocation may provide some explanation of the death of the fish, it is to be doubted whether it is the complete explanation.

A similar poisoning effect has recently (Stephens, 1949) been recorded from South Africa, where the offending organism, *Microcystis toxica*, is also a member of the Myxophyceae.

CHAPTER II

MAINLY HISTORICAL

THE use of seaweeds in certain parts of the world extends back into history for many hundreds of years: this is especially true in the case of China, Japan and Polynesia. At the present day Japan is perhaps the country where seaweeds appear to be of most significance to the well-being of the population, and prior to 1940 there was from the Japanese Empire a not inconsiderable export trade of substances manufactured from algae. The Chinese still use seaweeds or seaweed products on a relatively large scale, but for many years past they have mostly been imported from Japan. However, it is evident from references in the literature that in the past China had a flourishing seaweed industry of her own. On the coasts of both China and Japan seaweed has been used as agricultural manure since the dawn of crop cultivation.

China. From the general account of the seaweeds given in the last chapter, it will be realised that many of them, especially the red algae, are extremely elegant and often delicate in texture. This appearance must have impressed the early Chinese because their written character 海 藻 for the word alga (or

EDIBLE COMMON

seaweed) describes a thought that implies elegance or fine composition. Seaweeds played such a part in the life of the ancient Chinese that representations of them were used in decorations. Confucius, for example, refers to them as follows: "Tsang Wuăn kept a large tortoise in a house on the capitals of the pillars of which he had hills made, with representations of seaweed on the small pillars above the beams supporting the rafters." There are references also to seaweeds in the Confucian "Analects", and again in the classical Chinese "Book of History" wherein the Emperor says that he wishes to see the seaweed character embroidered on the lower garment.

A poem from the Chinese "Book of Poetry", written sometime between 800 and 600 B.C., is said to refer to algae, though from the context it would seem that fresh-water forms were meant rather than marine ones. The wording of the poem, however, makes it somewhat doubtful whether algae were really being mentioned: the context rather suggests aquatic phanerogams. In the following translation of the poem given by Chase (1942) the words duckweed and pondweed are said to refer to two different algae:

" The Diligence and Reverence of the young wife of an officer, doing her part in sacrificial offerings."

> She gathers the large *duckweed*
> By the banks of the stream in the southern valley.
> She gathers the *pondweed*
> In those pools left by the floods.
>
> She deposits what she gathers
> In her square baskets and round ones;
> She boils it
> In her tripods and stands.
>
> She sets forth her preparations
> Under the window in the ancestral chamber.
> Who superintends the business?
> It is [this] reverent young lady.

Roman Times. Although it seems evident that the algae have played a considerable part, both economically and aesthetically, in the Orient, they do not appear to have been regarded in a similar light by the peoples of the west. Virgil, for example, writes of "nihil vilior alga" or "nothing more vile than seaweed", which is hardly complimentary! Again, Horace, writing between 68 and 65 B.C., says "But birth and virtue unless [attended] with substance, is viler than seaweed". This contempt of the Romans for seaweeds is perhaps somewhat surprising when it is remembered that Roman ladies of those days used a rouge prepared from one of the species of *Fucus*, whilst Pliny the Elder (A.D. 23–79) refers to garments dyed purple with a seaweed extract ("phycos mallasion"). In more recent times the same idea, i.e. that seaweeds are useless, is perhaps reflected in the general lack of any reference to them in prose and poetry. One outstanding exception is in Longfellow's poem entitled "Seaweed":

When descends on the Atlantic
    The gigantic
Storm wind of the Equinox
Landward in his wrath he scourges
    The toiling surges
Laden with seaweed from the rocks.

Ever drifting, drifting, drifting
    On the shifting
Currents of the restless main
Till in sheltered caves and reaches
    Of sandy beaches
All have found repose again.

Chinese Medicine. Even though the early western world had no use for seaweeds there is no doubt that they were and still are highly regarded by the Japanese and Chinese. Both these races venerate the weeds of the seas, so much so that the former will go long distances, even to North Australia, in order to collect them. In the early days they were often, in addition to their other uses, employed medicinally, and the description of an alga in an ancient Chinese Materia Medica runs as follows: "The whole plant is officinal. Taste bitter and salt. Nature cold. Non-poisonous. The Hai Tsao [Chinese word for alga] grows in Tung hai [Shantung] in ponds and marshes. It is gathered on the seventh day of the seventh month and dried in the sun." The description of another seaweed reads: "It grows on islands in the sea, is of a black colour, and has the appearance of flowing hair." Unfortunately it is almost impossible from these descriptions to suggest the species of alga to which reference is being made.

After these early references there is apparently no further mention until we come to the 8th century, when two kinds of Tsao or algae were described in Chinese literature. One, known as "ma wei" or horse's tail, was fine-leaved and black in colour and grew in shallow water: the other kind had large leaves and grew in deep water and obviously referred to one of the Laminariaceae. There was also another alga with verticillate leaves that was called "hair of the head vegetable", a name which is nothing if not picturesque! About this time also a seaweed preparation called K'unpu was produced and used medicinally for dropsy. The description of the seaweed involved suggests that a species of the laver, *Porphyra*, was employed. One of the Laminariaceae, possibly *L. japonica*,* a red seaweed *Gracilaria lichenoides*, and

* In the literature it is described as *L. saccharina* but this species is not now regarded as occurring in Japanese waters.

a laver called *Porphyra coccinea* (=*Porphyropsis coccinea*) are all described in an 8th century-Chinese Materia Medica. Of *P. coccinea* it is noted that when taken in excess it "produces colicky pains, flatulence, and eructation of mucus"!

From the medical point of view the extensive use of seaweeds as food by both the Japanese and Chinese has probably contributed much towards preventing the development of goitre in these two countries, because the iodine in the seaweed stimulates the thyroid glands into activity whereas when these glands remain quiescent goitre results. In these early days other seaweeds, apart from those already mentioned, were also employed medicinally, e.g. a seaweed called Lung-she-ts'ai was used in China for abscesses and cancer, whilst in Upper India another one named Gillur-ka-putta was employed as a remedy for bronchocoele.

Seaweed as Manure. Although algae were known and prized at a very early date in the Orient, several centuries elapsed before mention was made of the use of seaweeds in western lands. There is, however, a brief reference in the 4th century by Palladius* to the use of seaweeds as a partial substitute for manure. Much later, in the 12th century, we know that they were used as manure on the coastal lands of France and probably also in Ireland, Scotland and Norway. Three centuries later Camden (1586) says that in Cornwall the valleys were "of an indifferent glebe, which with the sea-weeds or reit [algae] commonly called *orewood* and a certain kind of fruitful sea sand they make so rank and battle [fertile] that it is incredible". Another author, Owen, writing about the same time, says of the drift weed in South Wales: "This kind of ore they often gather and lay in heaps where it heteth and rotteth, and will have a strong and loathsome smell; when being so rotten they cast it on the land, as they do their muck, and thereof springeth good corn, especially barley." A few lines further on he adds: "After spring tides or great rigs of the sea, they fetch it in sacks on horse backes, and carie the same three, four, or five miles, and cast it on the lande, which doth very much better the ground for corn and grass." A somewhat different use to which burnt seaweed (kelp) was put at this time is provided by a reference in Collingwood (1912) to its employment about 1569† in the smelting

* Wheeler and Hartwell (1893).

† This reference to the use of kelp in 1569 is somewhat puzzling because the production of kelp did not appear to commence in England until 1720 (cf. p. 49).

operations of German copper miners near Keswick in the Lake district.

In the 17th century decrees were even made by the French Government informing the coast dwellers exactly what seaweeds should be used. They were also instructed in the manner in which the algae were to be employed, originally only as a manure but in later years for soda manufacture as well. The district manured in Brittany and Normandy is a belt, a few hundred metres wide, adjacent to the coast, but for ages it has been famed for the quality of its vegetables. The crops have been so heavy that in the forties of the last century this belt was called the "ceinture doré," or golden belt, as compared with the less fertile inland country. This name is apparently still used to-day for the region of Saint Pol de Leon near Cape Roscoff, though of course the agriculture of the hinterland has been improved considerably.

Seaweed was also being used in the Channel Islands at this period. Falle, writing in 1694, says: "The winter *Vraicq* being spread thin on the green turf and afterwards buried in the furrows by the plough, 'tis incredible how with its fat unctuous substance it ameliorates the ground, imbibing itself into it, softening the clod, and keeping the root of the corn moist during the most parching heats of summer. In stormy weather the sea doth often tear up from the rocks vast quantities of this weed, and casts it on the shore where it is carefully laid up by the glad husbandman." So highly did the people of Jersey value their seaweed that there was an old proverb, "*point de vraic, point de hangard*", or, "no seaweed, no cornyard". The islanders used not only drift weed or "vraic vennant" but also cut weed or "vraic scie". This latter, however, could only be cut at certain times. In Guernsey in 1862 it had to be collected between July 17 and August 31, whilst in Jersey there were two periods, March 10–20 and June 10–20, the latter being regarded as a summer holiday.

The Giant Pacific Kelps. So far there has been no mention of the great brown algae of the Pacific. The first reference to the giant Pacific seaweed *Macrocystis* appears to have been in the 16th century, and then two centuries later there are several further references to it in the narrative of Cook's voyages. This alga was of particular interest to the early explorers, because in dense fog an encounter with its floating fronds was a certain indication of proximity to land and dangerous rocks, and especial

care could then be exercised. About a century after Cook that great botanist, Sir Joseph Hooker, who travelled extensively and later became Director of Kew, wrote at some length about this plant in his *Botany of the Antarctic Voyage*, and this is what he had to say about it:

"It is seldom that the history of an alga is likely to afford interest or amusement to the general reader, unless it be a positively valuable plant in an economic point of view. . . . However, the *Macrocystis* is so conspicuous, and from its wandering habits, often occurs so unexpectedly, that the attention of our earliest voyagers had been directed to it, and we are consequently led by our enquiries into its first discovery, to the annals of those perils and privations which have ever marked the progress of discovery or enterprise in the stormy seas of the South. "Nihil vilior Alga" is a saying more trite than true, and one which a seaman can never use; for these weeds often prove his unerring guide towards land, as they are to the direction of the currents (from noting the direction in which the fronds are floating); or become of more importance still in the case of the present plant; for it is, when growing, not only the infallible sign of sunken rocks, but every rock that can prove dangerous to a ship is conspicuously buoyed by its slender stem and green fronds, and we may safely affirm that without its presence many channels would be impracticable, and numerous harbours in the South would be closed to our adventurous mariners.

So many interesting points are connected with the *Macrocystis* that a book might be instructively filled with its history, anatomy, physiology, and distribution; whilst its economy, its relation to the vegetables and to the myriads of living creatures which depend on it for food, attachment, shelter and means of transport, constitute so extensive a field of research that the mind of a philosopher might shrink from the task of describing them."

In the first chapter a reference was made to *Pelagophycus*, the "elk kelp", which grows in the Pacific off southern California. This plant has been known generally since the days of the early Spanish navigators who sailed round to the west coast of North America. These navigators were constantly on the look-out for this seaweed, which, like *Macrocystis*, was looked upon by them as an unfailing sign of proximity to land. Thus, in an account of Anson's voyage of 1740–44 around the world, the following passage occurs: "And when she [the 'Manilla ship'] has run into the longitude of 96 from Cape Espiritu Santo, she generally

meets with a plant floating on the sea, which being called 'porra' by the Spaniards, is, I presume, a species of sea-leek. On the sight of this plant they esteem themselves sufficiently near the Californian shore, and immediately stand to the southward; and so much do they rely on this circumstance that on the first discovery of the plant the whole ship's company chant a solemn *Te Deum*, esteeming the difficulties and hazards of their passage to be now at an end; and they constantly correct their longitude thereby, without ever coming within sight of land." The specific name "porra" now given by botanists to this plant is therefore an ancient Spanish name.

Agar-agar. Not quite a century before Anson's voyage took place a very significant event occurred in connection with the production of agar-agar (cf. p. 89). This substance was originally produced in China and was only introduced into Japan in 1662. Since that time the agar industry in Japan has flourished increasingly until in 1939 that empire was the principal source of this valuable product. Even in 1903 there were 500 factories for the manufacture of "kanten" as it is called. In normal times there is little cause for concern if one country becomes the principal producer of a certain commodity, even though the raw material may be available in other countries. In war-time, however, such a source may become cut off completely and then other countries are forced to build up an emergency scheme for utilising their own natural resources. In the 1939–45 war agar supplies had to be manufactured in all the major belligerent countries from their own local seaweeds, and although the cost of the home-made article was probably more than would have been paid for that imported from Japan in peace-time, nevertheless it is now likely that at least permanent industries will be established in various parts of other countries.

The Rise of the Kelp Industry. About the same time as the Japanese were learning about agar the French were starting to use algae for industrial purposes. Some time in the 17th century the French peasants commenced the manufacture of soda, mainly from brown rockweeds, for use in the glazing of pottery and the manufacture of glass. The soda was not extracted directly but was obtained from a product known as kelp. This word is encountered frequently but it can have two meanings which need to be noted. In Europe and England the word usually refers to the burnt ash of brown seaweeds which may be either oarweeds or rockweeds. This is its original and correct

usage: in America, however, the word kelp is applied to the growing weed as well, e.g. the names bull-kelp, ribbon-kelp are indicative of such usage. One may therefore talk of kelp beds, as, for example, when referring to *Macrocystis* or *Nereocystis*. In this book both usages will be adopted depending on which part of the world is under consideration. The use of soda from kelp in the 17th century was so important that in 1692 Louis XIV gave to the Royal Company of Glass Manufacturers at Paris the sole privilege of cutting annually, between March 15 and September 15, for the next twenty years all the "kelp" weeds (Fucaceae and Laminariaceae) along the coast of La Hogue. The privilege had to be revoked in 1718, soon after the twenty years had expired, due to representations from those Normans who lived by the coast and who wanted to use these weeds for fertilising their farm lands.

The production of kelp ash in Great Britain did not commence until about 1720, but by the end of the century Scotland alone produced about 20,000 tons annually. The burning of seaweed to produce kelp was actually suggested in 1688 as a very suitable industry for the Orkneys, but it did not in fact commence there until 1722 when it was introduced by James Fea of Stronsay. The industry reached the Outer Hebrides between 1726 and 1735 and by 1800 had extended across the North Sea to Norway.

An early account of the process of manufacture in Scotland was given by Mitchell (1848) in the Transactions of the Royal Society. The industry was important because the production of iodine in the 18th century also had its origin in the kelp industry. Before the discovery of iodine, kelp was sought after as a substitute for an expensive substance called "Barilla soda" or "Salichord" which was prepared, especially in Spain, from certain salt-rich plants that grew on the shore. The kelp was not so good as the "Barilla soda" because of its impurities, but it served quite well in the manufacture of ordinary glass. The big fillip given to the kelp ash industry by the discovery of iodine did not eventuate until 1841, and then it only lasted to 1873, when the discovery of the Chilean mineral deposits more or less killed the trade. The first factory, belonging to M. Tissier, for the production of iodine from kelp, was built at Cherbourg in 1814, whilst another one, owned by the same firm, was established at Conquet in 1829.* By 1838, 1,200 families were engaged in

* Various French authors quote different dates for the establishment of the first iodine factory, but these discrepancies could be explained if they were referring to factories situated in different places.

Normandy in the collection of the weed supplies, and in 1873, when the industry received its death knell, it is reported that there were nine factories that used 20,000 tons of kelp ash annually.

Japan, as in the case of agar, entered late into the trade as compared with the western countries, but she soon outstripped them and was even producing considerable quantities as late as 1929. This rapid development can only be accounted for by the cheapness of labour. The following figures give some indication of the progress of the industry in Japan:

1900, manufacture of iodine from kelp started.
1914, 100 tons produced per annum.
1915–18, 249 tons produced per annum.
After the war, 75 tons produced per annum.
1929, 115 tons produced per annum.

The enormous amount of labour that must be involved in this industry can be gauged from the fact that it requires between one and two million tons of wet seaweed to produce 115 tons of iodine, and the Japanese do not use mechanical harvesters!

About the middle of the 19th century some persons in Europe concerned with the burning of seaweed for the production of kelp ash realised that the process was wasteful, and also, that as the weed had first to be dried, no use could be made of the great quantities thrown up in the winter because the weather made drying difficult. Therefore in 1862 the destructive distillation of seaweed was suggested (Stanford, 1862) in order to overcome the wastage in burning and to make available the wet undryable winter cast. However, the new process never really flourished, though as late as the first world war the United States Bureau of Soils started up an experimental kelp potash plant at Summerland in California, in order to demonstrate the value of the destructive distillation process.

Discovery of Algin. What may eventually prove to be an event of major importance in the utilisation of seaweeds was a discovery made by the same man who introduced the destructive distillation process. The event in question happened in 1883 when Stanford first prepared alginic acid. This is a mucilaginous material that is present in many of the larger brown seaweeds, and which has a very complex structure. It was not properly prepared until 1886 and the exact formula has been in doubt until very recently. Alginic acid, its preparation, uses and potentialities will be discussed more fully later (cf. p. 192).

From early times medical science maintained an interest in the algae, and up to the end of the 18th century vermifuges in the western hemisphere were made from red, lime-encrusted seaweeds that looked like corals, hence their generic name *Corallina*. After 1775, however, they were replaced by another red seaweed called "Corsican moss" (*Alsidium helminthochorton*), the use of which was discovered by a doctor working in the Mediterranean. This alga is of more than passing interest, because it is believed to be the same vermifuge as that used by the ancient Greeks. The Chinese also employed algae as vermifuges, but instead of using a single kind they had a concoction composed of one green, one brown and seven red seaweeds!

Despite all these early usages it was not until the 18th century that botanists began to write about the economic uses of seaweeds. One of the earlier statements was that by Linnaeus who, in his description of a journey through Gotland in South Sweden in 1745, recounts how boiled bladderwrack is mixed with bran and fed to pigs. Almost a century later Greville (1830), who might be regarded as the father of British algology, noted that dulse or *Rhodymenia* was much liked by goats and sheep in Norway; thus the plant got its popular name in Norway of "sou-soll", whilst Bishop Gunner also gave it the Latin one of *Fucus bovinus*. About the time that Greville was writing, Irish moss (*Chondrus*) had a vogue in England as a fashionable remedy for consumption, but it had also acquired other important uses (cf. p. 155), and there was a flourishing export trade to the New World from Ireland and France. This, however, was not permitted to last for long. In 1835 the then mayor of Boston, Massachusetts, pointed out to his fellow citizens that they possessed considerable quantities of Irish moss, and that there was really no need to import it from Europe as they had been doing. Thus was born the Irish moss industry at Scituate in Massachusetts. In 1880, 450,000 lb. of this seaweed were collected and in 1898, 770,000 lb., but by 1912 this total had dropped to 212,000 lb. and in 1924 it had dropped yet further to 115,900 lb. The effect of the worthy mayor's proposal was very pronounced, because Irish moss that cost one dollar a pound in 1835 only cost 25 cents in 1853, and was down to 3 cents a lb. in 1880.

Pacific Algae and Potash. It was not until 1902 that Americans also realised that the huge forests of giant seaweeds in the Pacific represented a vast potential source of raw material for the

production of potash. Even with the advent of this realisation, it was 1912 before the production of fertilisers and salts of potash on a large scale from this source was begun. The war of 1914–18 materially increased the demand for potash and fertilisers, and it was also found that acetone, a very valuable war-time commodity, could be obtained from the giant seaweeds. As a result the Pacific coast industry flourished exceedingly during the war and 10 per cent of American potash requirements were thus obtained as well as the acetone. After the war the new industry could not compete with the manufacture of potash from other sources, and by 1923 it was moribund.

War-time Uses. In the 1914–18 war there were other uses for seaweed products, and there is no doubt that in the recent war even more use has been made of them. In the first world war grenades were sealed with the dried stipes of the oarweed, *Laminaria cloustoni*, but when these were used in a moist atmosphere the *Laminaria* stipe absorbed some of the water, swelled up and pushed in a pointer that ignited the charge. Algin (alginic acid) was used as a binder in the manufacture of cartridge primers, whilst extracts from the red seaweeds were used to supplement foreign gums, which could not be imported in normal quantities. In other directions it was found (1918) in France that horses occupied in heavy work thrived when their oat feed was largely replaced by dried rockweed meal made from *Fucus*. In order, however, for this change of diet to be successful, a short period of adjustment was essential, whilst the experimenters also found that it was difficult to acclimatise the horses to their new food. The horses never really ate it with relish, but the meal must have been of value because they increased considerably in weight as compared with similar animals fed on hay. However, the timely end of the war prevented this proposed change of diet from being widely adopted. As a further commentary on this matter, it may be added that in 1939, reports from the Auckland Zoo in New Zealand showed that the mortality rate had been lowered and the birth rate of the inmates increased by feeding them on kelp.

This brings the story of the uses of seaweeds up to the present era, but further details will be found in connection with the different industries as each is described in turn.

CHAPTER III

THE KELP INDUSTRY AND IODINE

In discussing this industry it should be remembered that the word "kelp" in Europe refers primarily to the burnt ash of seaweeds, and that it has only subsequently been extended to apply to the actual seaweeds themselves. In America, however, the large brown seaweeds are regularly known as kelps as well as the ash that is prepared from them.

Species Employed. In Europe quite a number of brown seaweeds have been employed in the manufacture of kelp. First and foremost there were the species of *Laminaria* and *Saccorhiza bulbosa*, though their usage was largely confined to areas where enormous quantities were regularly thrown up by storms, e.g. Western Ireland and Scotland. Next in importance were the common rockweed species, *Fucus vesiculosus*, *F. serratus* and *Ascophyllum*, which could be cut off the rocks and piled up on the shore. They were more satisfactory in some ways because supplies could always be obtained when the tide was out, and the peasants were not dependent upon an intermittent supply of material, as in the case of cast weed. On the other hand the work of collecting was harder and more arduous because the rocks were not easy places upon which to work, whereas carts could be driven on to those sand beaches where big casts collected. In the middle of the 19th century, when kelp was principally being produced from the oarweeds because of the iodine they contained, the kelp workers were put on to cutting rockweed during the winter months, although the grade of kelp produced was much poorer. In this way, however, the burners were occupied during the off-season.

Another species that has been used in the kelp industry is the "button weed" or *Himanthalia lorea*, so called because the perennial portion is a ~~small button-like~~ structure from which a long branched thong grows out each year. There was also the bootlace weed or *Chorda filum*, sometimes known as "sea-twine", which has the ~~appearance~~ of a brown bootlace and may reach many feet in length. This plant usually grows below low-

water mark in places where the bottom is rather sandy and the water is more or less quiet. It can, however, be thrown up on the beach in great quantities. Both the species mentioned above were apparently particularly favoured in the Orcadian island of Westray (Neill, 1904). Another of the sublittoral species to be utilised was *Halidrys*, the "sea-oak", but this only occurs in small quantities and then but locally. "Badderlocks", or *Alaria esculenta*, was also used but not to any great extent.

Products. Kelp was originally produced for the soda that it contained, but later the industry was revived on account of the discovery of iodine. It is interesting to note how the change of end product resulted also in a change of raw material. The brown rockweeds formed the principal source of supply for soda because they contain a higher percentage of this substance than the oarweeds, but the burners turned almost wholly to drift-weed (*Laminaria* species) when iodine was required because the oarweeds are much richer in this substance. The difference in value between these two sources is illustrated by prices paid for kelp in 1840, when iodine manufacture in Great Britain was just commencing: kelp manufactured from cutweed (rockweed) fetched £2 5s. per ton, whereas that from driftweed was worth £4 per ton.

In the early days of the industry, after the rockweed had been burnt, the kelp ash was bought by industrialists who wanted it for use in the manufacture of soap, glassware and alum, because of its richness in soda and potash. Indeed in the 18th century kelp was the principal source of the European supplies of these two commodities.

Quantities Produced. Some idea of the enormous quantities handled may be illustrated by a statement of Stanford's (1862), that at the beginning of the 19th century 20,000 tons of kelp were produced annually in the Hebrides alone. In recent talks with the crofters of these islands the author was informed that 80 carts, making a total of about 20 tons of wet weed, yielded one ton of kelp, so that 400,000 tons of wet weed would be required to produce 20,000 tons of kelp. This estimate is confirmed by various writers on the subject, who say that 100 tons of wet weed were required to produce five tons of kelp, or that 20 tons of wet weed produced five tons of dry weed and one ton of ash. It is difficult to understand how the coastal population of these islands was able to collect that enormous quantity of weed and treat it during the summer, without the aid of any

mechanical appliances. The author of the *Report on Home Industries in the Highlands* also felt the same difficulty, and he concluded that an output of 12,500 tons was a more reliable estimate. It is evident, however, that the larger figure refers to the early period when rockweed was principally being used. The tonnage gathered almost staggers the imagination, because in order to collect 400,000 tons it would take about 3,000 cutters approximately four months of hard work, if allowance is made for adverse weather and tidal factors. This great quantity of rockweed apparently included that gathered in the isles of Coll and Tiree. The industry was particularly flourishing at one time in these two islands, and Stanford himself controlled a factory there. It is of historical interest to note that among these inner islands Tiree adopted the industry in 1746, Coll in 1754 and Jura in 1762.

The comparative apathy of the Hebridean crofters to-day contrasts unfavourably with the energy that their forebears must have possessed. Indeed, even in 1911 Macdonald considered that the crofters were lazy and did not work well nor did they realise the possibilities of the industry. This apathy is no doubt in part due to the economic fluctuations that have always been associated with the trade.

At a later period in the industry the annual collection in Scotland, Normandy and Norway only totalled 400,000 tons of wet weed, 100,000 tons of this being gathered in France. In addition to these three main centres small quantities were also burnt in Sweden, Denmark, Spain and Germany. In the next chapter details will be given of a similar industry on the Pacific coast of North America.

Economics of the Industry. Complete understanding of the development of the Scottish industry cannot be attained without studying the economic changes that took place. It is therefore of more than passing interest to follow the fluctuations in the Scottish prices for a ton of kelp.

Early years, 1722–1740 £1 1s. 0d. (This low price was due to inferior calcining.)

1740–60	..	£2 5s.	1804	..	£7–£9
1761–70	..	£4 4s.	1806, 1807	..	£16–£18
1771–80	..	£5			
1781–90	..	£6	1808–9	..	£16–£22
1791–1800	..	£9–£10	1810	..	£16–£18

If we take 12,500 tons as the more probable maximum output in

the early years of the nineteenth century, then at an average price of £16 the income of the landowners would be £200,000. The average cost of production per ton during these years is reported as £2 7s. 6d., which represents £28,750 paid to the crofters for their labour. As about 4,000 families were involved in kelp manufacture this means that each family made £7 per annum! Some idea of the sums made by landowners in these times can be gauged from the fact that between 1770 and 1820 the shores of North Uist alone were let at an annual rental of £7,000. Out of their enormous profits the landowners were only expected to provide supervision and the necessary shipping to convey the ash to Glasgow.

Round about 1810 the importation of Barilla soda commenced and the price of kelp immediately dropped.

	Per ton		*Per ton*
1815 ..	£10–£11	1821 ..	£6 10s.–£11
1816 ..	£8–£10	1822 ..	£4 10s.–£9
1819 ..	£9 9s.–£11 11s.	1823 ..	£5–£10
1820 ..	£8–£11		

In 1820 the duty was taken off Barilla and this occasioned a further drop in the price of kelp. During the heyday of the industry the population of the Outer Hebrides engaged in the manufacture of kelp increased by about one-third, and no one appeared to foresee the possibility of a drop in price. As a result of the fall in price between 1812–25 the annual profit in South Uist fell from £15,000 to £5,000, and much of the labour had to be directed to other industries. The following figures show how the price fell still further between 1824 and 1840.

1824 ..	£6–£8	1831 ..	£2 12s. 6d.–£5
1825 ..	£7	1832 ..	£5
1826 ..	£4–£7	1833 ..	£4 2s. 6d.–£4 10s.
1827 ..	£5–£6	1834, 1835 ..	£3
1828 ..	£3 7s. 6d.–£4 15s.	1836 ..	£3 15s.
1829, 1830 ..	£4 16s. 8d.	1837 ..	£3
		1840 ..	£2 10s.

At the beginning of this period 3,500 tons were produced annually in the Orkneys, but by 1840 their output was only 500 tons.

The next part of the story cannot be told better than in Stanford's (1862) own words: "It [kelp] was used up to 1845

in the soap and glass factories of Glasgow for the soda. Large chemical works were then existing in the island of Barra for the manufacture of soap from kelp, and [by 1841] a very large sum of money was lost there. . . . The manufacture of iodine salts and potash then began to assume some importance, but the kelp required was not the same, that which contained the most soda containing the least iodine and potash. Chloride of potash, the principal salt, was at one time worth £25 per ton. The discovery of the Stassfurt mineral speedily reduced this price to about a third, and the further discovery of bromine in the same deposits also reduced the price of that element from 38s. per pound to 1s. 3d., its present price [1862]."

For the two years 1860–62, Scotland produced annually 4,350 tons of kelp, which sold at £3 17s. od. per ton, with a total value of £16,775; Ireland produced 6,080 tons, which sold at £4 2s. od. per ton with a total value of £25,005. In all, 10,430 tons were thus made from about 200,000 tons of wet weed and the total value of the kelp was £41,780. At the same time France was producing 24,000 tons annually.

Stanford (1877) considered that the iodine industry in these early years faced great difficulties, due to the temptations offered to speculators on account of the wide fluctuations in the price of iodine. The truth of this statement may be illustrated by the following table, which gives some idea of the great range in price between 1841 and 1866 together with the amount of kelp produced.

	Tons of kelp		*Price of iodine per lb.*	
Years	*Av.*	*Range*	*Av.*	*Range*
1841–45	3,133	1,887–6,086	11s. 9d.	4s. 8d.–31s. 1d.
1846–55	5,811	3,267–11,421	12s. 11d.	8s. 8d.–21s. 3d.
1856–65	9,730	6,349–14,018	8s. 10d.	5s. od.–13s. 8d.
1866–75	9,187	8,116–10,923	15s. 11½d.	10s. od.–34s. od.

After 1875 the price of kelp continued to fluctuate but it never again rose to great heights. The decrease in the Orcadian output between 1840 and 1873 was partly due to a decrease in the amount of labour available. Throughout the same period the annual value of the ash produced in South Uist remained at about £9,000, but in 1878 it had dropped to £1,329. From then onwards the crofters complained that the rents for stores and the royalties were excessive, and by 1891–94 the industry was somewhat disorganised. The royalties were then fixed at 10s. od. per ton of kelp and 1s. 6d. per ton of dried tangle, but

by 1901 the royalty on the ash had to be reduced to 5s. 0d. per ton. Even so it has been estimated that between 1907 and 1911 the crofters received more than double the money they earned during the period 1884–93. In 1911 the annual value of the ash in South Uist was £4,094, and at the then price of £5 per ton some 818 tons were produced. From then onwards the Scottish industry was slowly petering out, and the end of the story was reached about 1933 when the last cargo is reported to have left South Uist.

Adulterants. The kelp ton was not composed of the usual 20 cwt. In the Hebrides it was taken as equivalent to 22½ cwt. in order to allow for moisture and adulteration, presumably sand or stones. The Orcadian manufacturers must have been more expert because no allowance was made for adulteration, and the ton was taken as equivalent to 21 cwt. This was based on the assumption that good kelp should not contain more than 5 per cent moisture. Apart from adulterants and the presence of moisture, the method of manufacture also affected the quality of the kelp; Hendrick (1883) provides some data which illustrate the difference in composition between well and badly prepared kelp.

	Good kelp	*Poor kelp*
Potash	15·1–21·95%	5·75–8·5%
Soda	13·7–16·85%	2·55–10·05%
Iodine	0·55–0·67%	0·1 –0·3%

Since many of the factories for the manufacture of soap and glass were situated at Glasgow, it was but natural for that city to control the kelp industry. At one period four-fifths of the Scottish kelp were handled by a single Glasgow merchant, a Mr. William Patterson. Later, when iodine was obtained from kelp, the world's supply of that commodity was automatically controlled also by Glasgow. Much of this control still remained even when iodine was manufactured from the Chilean mineral deposits.

Manufacture in Scotland. Although the manufacture of kelp started in the 17th century in France, from whence it spread to Scotland, it was not until 1722 that the first cargo of kelp left the Orkneys, but by 1790, 3,000 tons were being produced each year by these islands. At first the Orcadians were so violently opposed to the industry that police protection was necessary for those engaged in the trade. A number of trials took place, and

the defendants pleaded "that the suffocating smoke that issued from the kelp kilns would sicken or kill every fish on the coast or drive them into the ocean far beyond the reach of fishermen; blast the corn and grass on their farms; introduce diseases of various kinds; and smite with barrenness their sheep, horses and cattle, and even their own families."

Later, when the crofters had abandoned their opposition to the industry because of the income it brought them, the kelp trade provided a livelihood for 60,000 people in the Hebrides, Orkneys and Highlands, and it was so important economically that the old toast in the Highlands was "a high price to kelp and cattle".

Barry, in his *History of the Orkneys* (1808), gives an account of the industry in his time. Three thousand persons were then engaged in the manufacture of kelp and each one made about a ton of kelp per annum. The use of kelp for iodine manufacture had not been introduced, and the crofters could only have been using cut rockweed because Barry complains of the waste of all the cast weed. Those who devoted their whole time to the burning of seaweed became very expert, and it was said that they could even make good kelp from weed that was poor in potash and soda. On the other hand those who attempted to combine farming with kelp manufacture were not so fortunate. Barry says that "manufacturing farmers seldom acquire skill in either profession, as their attention is divided between them; and as they trust to both for subsistence, sometimes the one may fail, and sometimes the other; their spirits sink with the losses they sustain, and then both their farms and manufacture are neglected".

The process of manufacture in Scotland varied but little throughout the two centuries the industry was in operation. During low tide rockweed (species of *Fucus* and *Ascophyllum*) was cut by hand (Plate 6) by means of bill-hooks with saw-like edges, and the cut weed, after being floated ashore on the incoming tide, was carried up and thrown into piles above the reach of the tide. Later on it was laid out to dry on the dunes or fields just above high-water mark. In the Outer Hebrides these dunes were also used for cultivation but a strip near the sea, known as the machair, was always left untouched for the drying of the weed. In addition to the cut rockweed, cast weed, mainly consisting of Laminariaceae, was also carted up and set out to dry.

In order to obtain the best results the cast had to be collected

as soon as it was thrown ashore, otherwise it rotted, or else was taken out to sea again if the direction of the wind changed. After a severe on-shore gale, therefore, all the families turned out and brought up as much of the cast as they could. In the Orkneys when a "brook of ware" was thrown ashore it was divided up among the tenants according to local regulations. Thus the actual proportion was allotted on the basis of rent paid or acreage of land held, but the actual area for collecting on the beach was determined by lot. In the island of South Uist the crofters built special low walls, composed of loose boulders from the shore or of sods of earth, upon which they spread out the weed to dry (Plate 8*b*). In hot weather during the summer the weed could be burnt after forty-eight hours of drying if it had been turned at frequent intervals. Since rain washed out the soda, potash and iodine, the stacks of dried weed and the weed in process of drying had to be protected during rainstorms. This was one reason why air-drying could never be successful in the winter. The loss of salts due to rain might be considerable; for example, Gloess (1919) reports that whilst 9 kilograms of weed normally yielded about 8 grams of iodine, after being washed by rain less than one gram would be obtained.

Whilst the drying was in progress the kilns were prepared nearby. At the very start of the industry kilns were not used and the dried weed was burnt in open heaps or piles. This method proved unsatisfactory as the ash was then contaminated with foreign matter such as sand and gravel. The kilns, which were constructed of stones from the beach, were circular in shape and about two feet in diameter. Sometimes cylindrical kilns were used that were two to two and a half feet high and eight to eighteen feet long. Although no burning takes place to-day remains of these kilns can still be seen in the Orkney Islands. When the material was dry enough and ready for burning, the crofters first burnt a small amount with brushwood or peat in order to start the kiln, and then when this was burning well they kept adding more and more dried weed until the kiln was full or until all their material had gone.*

The final product after burning was a hard solid cake, three to six inches thick, because the ashing temperature was so high that the residue melted but solidified on cooling. When the

* The kelp obtained in South Uist showed that if good results were to be obtained, much more experience was required in burning the leafy 'may cast' (cf. p. 58) than the dried stipes of the winter cast.

kelp was being used as a source for iodine, the high temperatures obtained were actually unsatisfactory because they caused much of the iodine to volatilise and this decreased the value of the kelp. The iodine content of the ash depended very largely on being able to stop the burning at the right moment, the difference being of the order of 6 lb. of iodine per ton. The ideal product was also a loose ash rather than a hard slag. If the kiln was not full of ash after the first burning, the crofters went on with successive burnings until they had a cake of ash fifteen to twenty-four inches thick and weighing from two to six cwt. The solid mass was finally broken up whilst hot by throwing water on to it. At the end of the season the material collected was, in the early days, sold to the glass manufacturers and then at a later period to the iodine factories.

It is evident from this account that the raw material is abundant enough, but the success of any industry connected with seaweeds depends on being able to collect and dry the weed cheaply. This is not so easy as it would appear, especially if the workers lose an entire crop through bad weather at the drying period. In any event manual labour is relatively expensive and some form of mechanical harvesting is essential.

Manufacture in Ireland. When a scientific survey of Clare Island in Western Ireland was carried out in 1912, Cotton noted that weed for burning was still being actively collected (Plate 8). The stipes, or "rods" as they are known in Ireland, were collected during the winter and put on stone walls, as in Scotland, to dry. During February and March more weed was cut by hand, and then between April and June the "may leaf" was garnered. After storms in the spring the rods were kept for burning whilst the leaf was separated out and put on the land as manure. Experience showed that if rain fell on to plants of *Laminaria saccharina* whilst they were drying they bleached very rapidly and were then of no further use for kelp. *Laminaria digitata* on the other hand bleached less readily, whilst *L. cloustoni* turned a reddish-brown. In addition to the oarweeds the Irish Board of Agriculture also recommended the use of badderlocks (*Alaria*) or murlins, as it is called in Ireland, and sea-oak (*Halidrys*). *Ascophyllum* and *Fucus* were generally rejected because of the small amount of iodine they contained.

In Ireland driftweed belonged to the Crown or to persons possessing a charter from the Crown. The cutting of the oarweeds was free to everyone but the cutting of rockweed was a

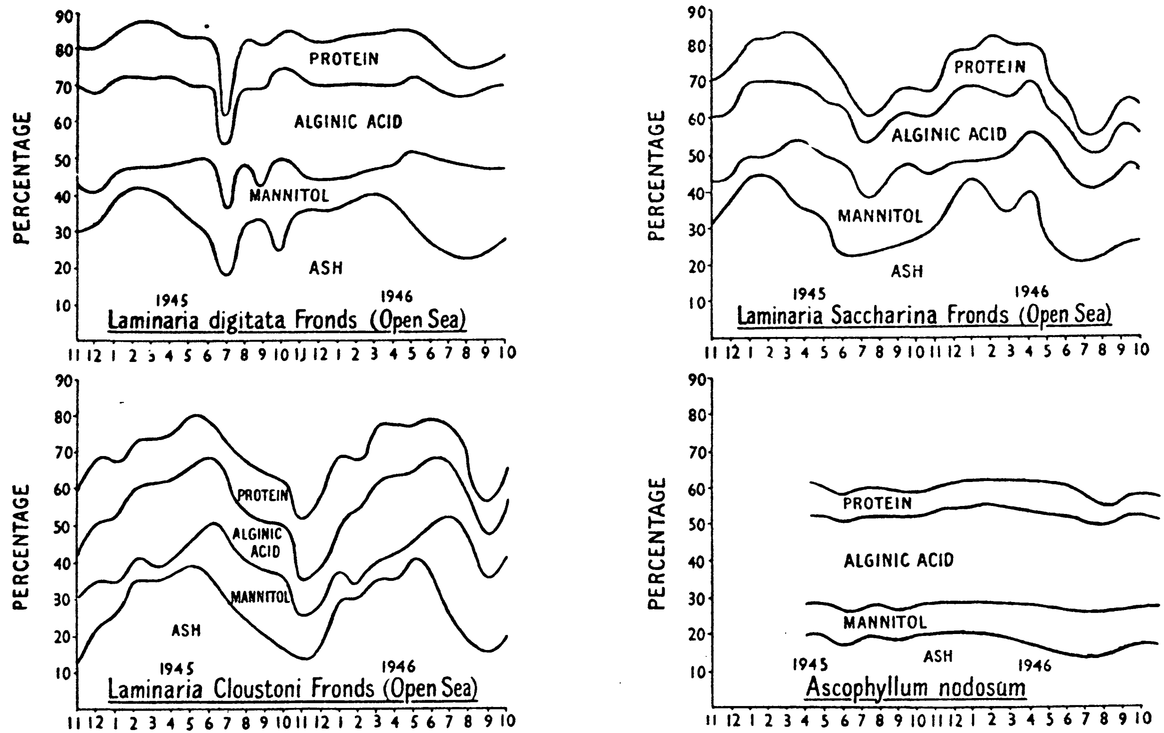


FIG. 17. Seasonal variation of the ash and some organic constituents of the fronds of *Laminaria* spp. and *Ascophyllum nodosum* (Annual Report, S.S.R.A., 1946)

jealously guarded privilege. At the time of the Clare Island survey the rockweed was still being cut extensively for use as manure on the land (cf. p. 136).

In the 19th century much of the Irish kelp was shipped to Glasgow for the extraction of the iodine. Stanford, who had much to do with this industry, found that the Irish were not above sharp practice, because he says (1884) that "it is not uncommon to find a block of granite carefully varnished over with a thin veneer of this material [kelp]. Our Irish friends are specially partial to lucrative practical jokes of this description."

Manufacture in France. In France, where the industry originated, castweed, rockweeds, and then later oarweeds, were all used. In the early stages of the industry the peasants utilised all the brown seaweeds in the cast, which was known as "goémon épave" or cast seaweed. The special May cast, composed almost wholly of old fronds (cf. p. 58), was known as "goémon rouge", "goémon d'avril" or just as "mantelets".* It was the tradition that the men were responsible for the collection of the seaweed, whilst the women, children and the aged busied themselves with the kelp burning. Some of the places in France drew up local regulations for the collection of driftweed. For example, in the Isle d'Ouessant the inhabitants of the nearest village came down after a gale and the oldest inhabitant marked out the drift into equal portions. Each family could then take as many lots as there were members in the family, but they were only allowed to remove the weed during daylight, or, as the regulations put it, "when the lighthouses are extinguished".

In the days of the iodine industry the oarweeds, known as "goémon poussant en mer" or "goémon de fond", were cut by special workers who were known as "goémonniers" or "soudiers", but before they could operate these people had to obtain special licences. These men used small boats, each capable of carrying ten tons, whilst their weapons were sickles attached to long poles and known as guillotines: these were used to cut the plants near the top of the stipe because it made for ease in handling.† Sauvageau (1920) describes the work extremely well when he says "Ce travail demande de la force, de

* According to Gloess (1919) the French use different names for the two principal species of *Laminaria*: thus *L. digitata* (*L. flexicaulis*)—Anguiller, Foue, Toutrac or Tali, and *L. cloustoni*—Mantelet, Calcogne, Cuvy or Tali-peu.

† Gloess (1919) suggests that the goémonniers might be able to obtain three crops a year because of rapid regeneration. There is no evidence that such a course would be at all possible

l'addresse et de l'habitude". Delage (1913) said that normally half the goémon cut was not picked up by the goémonniers in spite of their skill, whilst Deschiens (1926) considered that under bad weather conditions as much as 80 per cent of the material cut would be lost. Much of this weed, however, was not irretrievably lost, because sooner or later it was washed ashore and doubtless collected by another village. Sauvageau also prophesied, and the prophecy has already been fulfilled, that a time would come when mechanical appliances would be used for cutting *Laminaria* in Europe (cf. p. 200). During his lifetime mechanical harvesters were only employed on the Pacific coast of North America.

In France the dried weed was burnt in shallow pits, six to ten metres long, about two feet wide and two feet deep. The sides were built up roughly with stones from the beach and in some places the trench was divided up into compartments. Each of the compartments was packed tightly with small pieces of the dried algal mass and set alight. Because of the more favourable climate the ovens could be in use for a longer period each year than in Scotland, and normally they were in action continuously from July until the end of September. The ash obtained in France was known as "Soude de Varech" or "soda of wrack". The word "varech" or "vraic" is said to be derived from the English word wrack and to have been introduced into France at the time of the Norman conquest of England.* The use of "soude de varech" was proscribed in French soap works and laundries because it was much inferior to Barilla soda. The lye was not regarded as strong enough and, furthermore, the iron impurities stained the cloth. It was therefore principally used in France for the manufacture of glass.

In France, as in the Orkneys, the industry had its opponents, because in 1769 there were complaints from the farmers that the fumes from the kilns damaged the fisheries and the adjacent orchards. It was proposed therefore to restrict kelp burning to the region around Cherbourg. Not unnaturally considerable opposition was raised to this proposal, and so the Academy of Sciences sent out a commission of three of its members to investigate the complaints. They naturally found that these complaints had no foundation on fact, and their report bore fruit in 1772 with the establishment of more liberal regulations.

* In view of later indiscriminate usage Gloess (1919) suggested that the word varech should be restricted to the marine phanerograms and that goémon should be reserved for the algae.

From the economic aspect there are some interesting figures available about production of varech during the first world war. Guerin (1917) has recorded that in 1913 the French produced 3,000 cubic metres worth 5 francs per cubic metre. In 1915 2,000 cubic metres were produced and the price had risen to 8 francs, whilst in 1916 it had risen still further to 12 francs per cubic metre. This is reflected in the price for soda which in 1913 fetched 90–100 francs a ton and in 1916 was costing 250–350 francs a ton. French production figures for more recent years are provided in the following table:

	Tons		*Tons*		*Tons*
1913 ..	4·9	1919 ..	65	1925 ..	60[1] (from 125,000
1914 ..	1·2	1920 ..	45	1930 ..	88 tons wet weed)
1915 ..	9·3	1921 ..	39	1936 ..	55
1916 ..	18	1922 ..	30	1937 ..	90
1917 ..	31	1923 ..	61		
1918 ..	26	1924 ..	72[1] (from 180,000 tons wet weed)		

[1] Roman's (1930) figures for these two years do not agree with those of Deschiens (1926). Roman gives 54 tons for 1924 and 55 tons for 1925.

By 1937 the French industry was clearly doomed because Breton ash was being sold to Germany at 20 Rm. per kilogram, whilst one kilogram of the equivalent Chilean salt cost only 5 Rm.

In France kelp-making was largely confined to the Normandy coast at Morbihan, Finistère and the Côtes du Nord, with the principal production centres at Penmarch, Roscoff, Kerlouan, Port-sall, Pro-poder, L'Abervrack, Quiberon, L'Aber il Dut, Mollenc, Beniget Is., d'Yeu, d'Hedik, Jouat, Loctudy and Audierne.

Extraction Process. When the kelp ash had been obtained in any of the areas and sent to the factory, further operations were necessary in order to extract the soda, potash and iodine. The broken ash was first dissolved in water and then the solution was evaporated to dryness. This process was repeated a number of times and each time the concentration of the potash increased. Subsequent treatment then differed: in Scotland the final solution was either treated with lime in order to obtain the potash, or else sulphur was first removed by adding sulphuric acid, and then the ash was distilled with manganese dioxide when iodine volatilised off and could be collected. In France the iodine was obtained by the simple method of saturating the concentrated solution with the gas chlorine; this caused the iodine to be

deposited and, after being washed, it could be purified by heating it and collecting the fumes as they came off. A more modern method was a slight variation of the one described above.

Even when used carefully, in the case of iodine manufacture, the somewhat primitive methods of preparing the kelp that have been described above are wasteful, and proposals for obtaining a better yield were repeatedly made but were never widely adopted because of the conservatism of the peasants. There were various factors responsible for the poor results obtained. It was obviously uneconomic to use rockweed species because of their low iodine content, but if the castweed happened to be poor in quantity any one year, the peasants apparently considered that it was easier to go out and cut rockweed in quantity, rather than attempt to cut the submerged oarweeds. Another cause of low iodine content was the drying of the weed in wet or dewy weather, because this leached out some of the iodine-containing salts (cf. p. 146). There was also the influence of seasonal variations, but here there was not complete agreement among investigators as to whether the amount of iodine in the brown seaweeds was highest in the summer or winter. On the whole the results of analyses suggest that it is highest in the winter, so that if operations take place in the summer there must be some unavoidable loss. In *Laminaria digitata* Lunde (1937*a*) found that the summer content may be about 0·3 per cent, but that in the winter it may rise to 0·55 to 0·6 per cent, or almost double that of the summer. It is possible that in other localities the very reverse may hold. In view of the conflict in results it is evident that further investigations are desirable.

There is no doubt that much iodine was also lost through using too high a temperature during the burning of the seaweed, whilst another cause, which at first sight might seem peculiar, was the unavoidable admixture of sand with the dried weed. This collects when the weed is picked up off the beaches, and more may become admixed if the drying is carried out, as it frequently was, on sand dunes. The presence of the sand increased the loss of iodine by nearly 100 per cent at the red heat used to melt the ash. Vincent (1924) quotes experiments which show that when sand is present the loss of iodine is 50 per cent after 15 minutes at the red heat necessary to melt the ash, as against 29·3 per cent when no sand is present. After 30 minutes the iodine loss in the presence of sand is 82·2 per cent as against 40·94 per cent

without, and after one hour 90·44 per cent as against 86 per cent. From these figures it is clear that the admixture of sand is only of significance if the heating lasts for 30 minutes or less.

With the spread of the industry, some of the persons engaged in it realised that there are many substances in the brown algae that are normally lost in the course of ordinary kelp manufacture, but which, if the processes were modified, might be converted into valuable by-products. Numerous suggestions have been made for overcoming this problem, and various undertakings have been formed in different countries with this purpose in view. A number of patents have also been taken out for obtaining the maximum yield of iodine and salt whilst at the same time extracting other organic materials.

New Processes. The most important of these techniques is probably the destructive distillation or char process, which was first suggested in 1862 by the chemist Stanford. This process was designed not only to overcome the wastage of iodine but also to utilise the winter crop. In the life of a *Laminaria* plant there are two periods in its development when it gives rise to a considerable amount of cast material. Each year in the spring, about April, the cells at the top of the stipe become active, and they give rise to a new blade which becomes interposed between the stipe and the old blade. The union between the old and new blades grows weaker and weaker and during May and June the old blades are all cast off. These are washed ashore in great quantities and form what is known as "may cast" or "may leaf". Sooner or later, however, the oarweed plant grows old and senile, and in this state the adhesion of the holdfast to the substrate becomes weaker and eventually during a gale the plant is torn from its moorings and thrown ashore. Since gales normally occur during the winter months these old plants, usually about four to five years of age, are thrown ashore between November and March, and they form what is known as the winter cast. This differs from the may cast in the very high proportion of stems that it contains.

For the char process the castweed is collected at both seasons of abundance, and then either dried in the sun or by artificial means (Plate 8). It is next cut up and packed into closed iron vessels with long outlet tubes which are known as retorts. The retort is heated and the alga distilled at a low red heat. The material which vaporises is collected and separates out into tar,

ammonia and an illuminating gas. The charcoal left in the retort is broken up and water added to dissolve out the salts of soda and potash. From these salts iodine and bromine are prepared, whilst the charcoal residue that remains is useful because it is highly absorbent and is also an efficient decoloriser and deodorant (cf. p. 85). Unfortunately the equipment for this process is expensive and requires skilled labour to operate it, and the crofters, whilst excellent in the preparation of the weed, apparently did not readily become adapted to technical manufacture. The wet weed also needs to be brought to a central point where the factory is located and this involves transport costs. The crofters were also not interested in a process that required them to convey the weed some distance. In spite of these difficulties, however, the process has been employed in the Outer Hebrides, the island of Tiree and later on the Pacific coast of North America (cf. p. 84).

The efficiency of the char process over the kelp process can be gauged from the following table. Some information has been included here about a third process, also invented by Stanford, and known as the wet or "lixiviation" process, but this will be described in detail later (cf. p. 193) as it is of more importance in the production of algin. The figures in the table in all three cases are based on an initial quantity of 100 tons of wet weed.

Items	*Original burning process*	*Char process*	*Wet process*
Dry weed obtained and utilised (tons)	18	36	70
Crude ash (tons)	18	36	33
Salts extracted (tons)	9	15	20
Iodine extracted (lb.)	270	600	600
Kelp wasted (tons)	18	—	—
Charcoal (tons)	—	36	—
Tar, ammonia (tons)	—	some	—
Algin (tons)	—	—	20
Cellulose	—	—	15

Stanford, who originated the char process, gave an account of it in an address to the Society of Arts in 1862. In this lecture he sought to illustrate its advantages over the old process by showing the additional materials that he estimated could be extracted from one ton of kelp derived from different seaweeds.

	Laminaria digitata		*L. saccharina*		*Fucus vesiculosus*		*Fucus serratus*		*Ascophyllum*	
Old Process	cwt.	lb.	cwt.	lb.	cwt.	lb.	cwt.	lb.	cwt.	lb.
Potash ..	6	56	8	20	2	72	4	96	4	46
Soda ..	6	45	5	53	6	78	5	24	7	41
Ash ..	3	89	3	103	4	63	6	38	5	53
Iodine ..		12·5	—		—		—		—	
Additional with Char Process	galls.		galls.		galls.		galls.		galls.	
Volatile oil ..	$4\frac{3}{4}$		$4\frac{1}{2}$		$9\frac{2}{3}$		$6\frac{1}{2}$		—	
Paraffin oil ..	$4\frac{3}{4}$		$5\frac{1}{6}$		$13\frac{1}{6}$		$7\frac{1}{3}$		$14\frac{1}{3}$	
Naphtha ..	3		$2\frac{3}{4}$		$5\frac{2}{3}$		$2\frac{1}{2}$		—	
	cwt.	lb.	cwt.	lb.	cwt.	lb.	cwt.	lb.	cwt.	lb.
Amm. sulphate	1	46	2	17	2	34	2	38	3	108
Calcium acetate		$17\frac{1}{2}$		21		75		$36\frac{3}{4}$	—	
Colouring matter		$2\frac{3}{4}$		$5\frac{3}{4}$		$11\frac{1}{2}$		6	—	
Pure charcoal	8	35	8	59	15	10	14	41	20	49
Gas ..	3,615 cu.ft.		2,771 cu.ft.		4,313 cu.ft.		3,811 cu.ft.		8,272 cu.ft.	
Iodine ..	19·4 lb.		—		—		—		—	

Commenting on all these extra materials and the effect that their production would have upon lowering the costs Stanford says: "Can we wonder that the kelper works in rags? Can we be surprised that the operations are confined to desolate sea shores? . . . It is difficult for those who have not visited these coasts to form an idea of the vast accumulations of seaweed thrown up in the winter. . . . Is it possible that the utilitarian spirit of the age will permit this enormous waste to continue?" In spite of all his efforts Stanford met with difficulties on all sides. Considerable opposition came from the kelp workers, who were nothing if not conservative as the following little story will show. On one occasion he and one of the most experienced kelpers pitted themselves in a test in which Stanford with his new method was successful. The old kelper, not to be daunted, turned to him and said, "I have been making kelp for fifty years or more and am I to be taught by a young Sassenach with no beard on his face to speak of?"

Other scientists must have been sceptical because Mylius, some years (1876) after the introduction of Stanford's process, suggested in a scientific journal that it must be a failure because no further news had been heard of it. The next number of the

same journal contained a spirited reply from Stanford who offered to sell Mylius as much of the products as he cared to buy!

There was opposition also from the manufacturers. At a meeting of the Society of Chemical Industry in 1916 the following remarks on the distillation process were made by W. G. O'Beirne, director of the British Chemical Company: "One intended that the distillation process would furnish oils, light and heavy, alcohols, acetic acid, ammonia, an illuminating gas, but all that one has succeeded in obtaining was an evil-smelling tarry water of no commercial use; factories have been constructed in Tiree, North Uist and Clydebank, £40,000 has been sunk in them and all has been lost."

Criticism of this nature, together with the disappointing results, must have damped the ardour of even such an enthusiast as Stanford. It is possible that the failure of this process, both in Europe and America, has done much to prevent the brown algae being utilised on a large scale. However, as de Launay (1902) has said, old ideas often reappear, and so we find Tupholme (1926), in a report of Fuel Research Board trials designed to provide employment, studying Stanford's process anew. He concluded that in order for the process to work it must be thermally self-contained: his calculations showed that this result could be achieved and therefore he substantiated Stanford's work. However, Tupholme's experiments were only carried out on a small scale, but nevertheless he considered that the process would repay further work on a larger scale. The literature does not suggest that the matter has been prosecuted any further since then.

Numerous variations of the distillation or char method have been proposed. Thus, Moride (1866) suggested the use of a portable furnace that would carbonise the algae in the air, whilst the iodine was to be extracted subsequently by the use of benzine and alkaline hypochlorite. Another distillation method that was suggested by de Rousseau in 1882 involved burning the weed whilst wet in the presence of some alkali, and then dissolving out the iodine from the ash. In this process the weed was first bruised and next heated with an astringent in order to render the nitrogen insoluble. The "Compagnie Française de Iod et de l'Algine" invented a new technique whereby the salts were extracted from the algae with the aid of organic solvents.

Yet another process that has been employed required the seaweed first of all to be macerated or chopped up, after which it was heated under pressure. The liquid containing the soda and

potash was removed from the soggy mass by means of presses, and the organic residue was then used partly as a manure and partly for making technical products. There is a fifth group of processes in which the seaweed was first extracted with either hot or cold water: this was followed by a further treatment with lyes (e.g. slaked lime, hydroxide of magnesium), after which it was squeezed free of the liquids and the residue used for manures or technical products. At least two French companies and one Norwegian firm employed modifications of this process. Another French company extracted the iodine from the seaweed by using an acid, either with or without oxidation. This method resulted in the simultaneous separation of some organic materials, and after these had been recovered by precipitation they were used in the manufacture of paper (Hoffmann, 1939).

In 1850 the Pellieux process was introduced. An advantage of this method was that it could be operated throughout the year, but in order to obtain the maximum results only species of *Laminaria* were used. The algae were collected and allowed to drain in sheds for four to five days. They were then chopped up and laid out on a concrete floor and allowed to ferment for forty-eight hours. The drainage water throughout was carefully collected and when it had been evaporated down the iodine salt of potash was left. The fermented mass was treated with lime and then mixed with previously dried weed and heated in a retort. This removed various organic products and the ash that remained was broken up in water in order to extract more soda and potash. A modification of this process has been used by the great American seaweed firm, the Hercules Powder Company (cf. p. 87), and also by L. Dupont, in France. This method of fermentation has been shown to increase the amount of extractable iodine during the first three or four days, though not if prolonged further. It has been suggested that additional work on this aspect of the subject would be desirable.

An eighth process involved the preparation of a colloidal suspension from the fresh seaweed, and either the suspended organic material was separated off or else the dissolved salts were removed by a process known as exosmosis.* Finally mention must be made of a method used by the Russians because it differs fundamentally from all those so far described. The seaweed is first of all chopped up and then suspended in water, and an electric current is passed through the solution with an increas-

* Exosmosis is the process whereby the solvent is removed from a solution through a semi-permeable membrane.

ing rise of potential. During the first and second steps, i.e. at low potentials, the iodine separates out, in the third the bromine, and in the fourth, or at the highest potential, the chlorine. At the end the solution is concentrated and a seaweed alcohol known as mannite or mannitol collects at the positive pole and cellulose and alginates at the negative pole.

It can be seen from the above account of all the different processes that more and more care is being taken to secure the valuable organic by-products; so much so that in some cases they are now the chief products and the potash and iodine form the less valuable by-products.

Iodine from Seaweeds in Russia. Before passing on to consider the production of iodine in Japan, reference must be made to a rather interesting fact about Russian production. We have seen that everywhere, Japan included, the brown kelps and rockweeds form the source of the iodine and potash. In Russia, however, a red seaweed, *Phyllophora nervosa*, is collected in the Black Sea and treated industrially because of its richness in iodine.* The ash of *Phyllophora* may contain as much as 1·3 per cent of iodine and it is therefore as valuable as the species of *Laminaria*. Related species of *Phyllophora* occur on the coasts of England and France, but not in sufficient quantity to enable them to be exploited. It is reported that the Russians have invented special nets for the collection of this alga. The use of *Phyllophora* only commenced in 1927 when the Black Sea factory produced, according to Pentegow (1930), 2·2 tons of iodine per month. Prior to that date the Russians had operated factories during 1914–17 on the White Sea, Black Sea and at Vladivostock. These had all employed brown algae and, with the exception of the one on the White Sea, were closed down after the first world war. In 1929 the White Sea factory, located on Zip-Nawolek Island, was producing 3 tons of iodine per month, whilst an experimental factory erected at Bejuk-Schor-see was yielding 15–16 kilograms of iodine daily. Pentegow commenced a study of the seaweed supplies of eastern Russia in 1927 and concluded that at least 75,000 tons were available annually, mainly composed of *Laminaria japonica*. It is principally collected by means of "kanzas" or poles with prongs, though in Korea women dive down and cut off the plants with knives.

* A number of other red algae, mainly small forms of no economic value contain considerable quantities of iodine in special "iodine cells", "blasenzellen", or gland cells. In these species the iodine is present as a compound and not in the free state (see p. 229).

Natural drying is difficult because the weather is unsuitable and artificial drying is therefore necessary. Attempts to obtain more recent information about these operations have not proved successful.

Kelp Manufacture in Japan. Although the iodine industry in Japan did not start until the latter part of the nineteenth century, it is practically only surpassed by the iodine output from the mineral deposits of Chile. In 1929 according to Romans (1930), Chile produced 80 per cent of the world's supplies, Java 9 per cent and Japan 7 per cent, all the Japanese output coming from seaweeds. In the less important iodine-producing countries, e.g. France and Norway, it is also obtained solely from algae. In Japan the chief places for the manufacture of iodine are in the island of Hokkaido and the prefectures of Chiba, Kanagawa, Yamaguchi and Schizuoka (cf. Fig. 20). In 1903 the Yokohama *Shimpo* commented on the fact that Japan was then producing not only enough iodine to satisfy her own needs but also to have some available for export. Nevertheless the principal difficulty in extending the business was the labour involved in collecting the large amounts of weed necessary. A description of the methods employed in collecting these submarine algae will be given later (cf. p. 170), but it is astonishing how the people manage to collect the quantities they do. In Hokkaido only species of *Laminaria*, known as "Kombu", are used, but in the other places the favourite seaweeds are "Kajime" or *Ecklonia cava*, "Arame" or *Eisenia bicyclis*, and "Ginbaso" or *Sargassum*. The genus *Sargassum* is usually regarded as having originated in Japanese waters because the majority of the species occur there. This argument based on the number of species is often correct though it is by no means universally valid. To us, however, *Sargassum* is more familiar as "gulf weed", because *Sargassum natans* occurs in such masses off the coast of Mexico that it has given rise to the far-famed Sargasso Sea.

In Japan so much importance is attached to the industry that commercial firms have the privilege of cutting the weed in certain areas of the coast that are reserved for their use. The women collect the driftweed from the beaches, whilst the men go out in boats and cut it by means of bill-hooks fastened to the end of long poles, rather like the French goémonniers. The weed is dried on the shore in the sun and then heaped into long piles and slowly burnt. In some places the dried seaweed is charred in special furnaces from which the supply of air is partially cut

off. The ashes are collected and put into straw bags for sending to the manufacturers. The ash used to be sold by the weight and so the fishermen were said not to be over-careful in filling the bags, and sand and other foreign matter were frequently included! On arrival at the factory the ash is treated in much the same way as it used to be in Scotland. In the distillation part of the process the Japanese use permanganate of potash instead of manganese dioxide. The iodine product which comes over is not absolutely pure and requires to be refined.

The quantities produced annually are not unimportant when we remember that Europe manufactured 175 tons annually at the height of the industry. In 1914 Japan produced 100 tons, and the annual output rose during the first world war until in 1916 it was nearly 300 tons. Up to 1929, and probably more recently, iodine was still being produced in Japan and the following figures give some idea of the quantities involved.

Year	*Tons*	*Year*	*Tons*
1902	1·8	1916	294
1903	15	1917	216
1904	30	1918	227
1905	50	1919	249
1911	60	1920	75
1914	100	1929	115 (75 tons used in home consumption)

Chemical Composition of Kelp Seaweeds. At this stage it is desirable to consider the proportion of iodine present in the different seaweeds and in the ash derived from them. The form in which the iodine is present in the living plant is not of immediate concern: according to some workers (Okuda and Eto, 1916), it is present chiefly in an organic form, whereas according to others (Kylin, 1930, and Trofimow, 1937) it is present as inorganic iodine.

Many of the seaweeds and some of the fucoids exhibit the phenomenon known as iodovolatilisation, or the liberation of free iodine (Dangeard, 1929, 1930, 1931; Freundler, 1924). This is the basis of their value for iodine extraction, though the phenomenon is only exhibited in certain areas, e.g. plants from the Baltic do not show it (Kylin, 1930). The iodine is produced in the epidermal cells and basal portion of the blade and is associated with meristematic activity. The amount available varies from season to season, and is also affected by immersion, cutting, exposure, wave action and variations of temperature. The actual escape of the free iodine is due to the action of iodide-

oxidases acting in the presence of oxygen. No quantitative data are available and this subject would seem worthy of future investigation, especially in the form of regional studies.

Analyses of the algae used commercially have been published by a number of investigators, but the results are by no means uniform. This is only to be expected, because the iodine content of the fresh weeds will vary at different seasons of the year and also with locality. The analytical results will also depend upon the relative proportions of frond and stipe in the sample and whether the plant is fruiting or sterile. It is possible also that the presence of epiphytes, e.g. Bryozoa and Rhodophyceae, may affect the results. Similarly the proportions of potash and iodine in the kelp will vary, depending on the species of weed used, the time of year and the amount of care devoted to its manufacture. The Scottish kelp, for example, was regarded as poor whilst the Irish kelp was richer because it was made at a lower temperature so that less iodine was lost. Kelp made in Guernsey was even better. All these criticisms of the earlier analyses have been advanced by Sauvageau (1918) in a caustic paper, and too much weight cannot be placed upon the figures that are available.

It is also interesting to note how the iodine contents of the Japanese seaweeds compare with those of the European species, and so the table below gives the relevant data for Japanese algae.

Seaweed	*Locality*	*% iodine in raw weed*	*% ash in weed*	*% iodine in ash*
Kajime } *Ecklonia*	Chiba	0·23	54·8	0·4
Kajime } *Ecklonia*	Yamaguchi	0·25	47·2	0·5
Arame *Eisenia*	Yamaguchi	0·3	50·9	0·5
Ginbaso } *Sargassum*	Yamaguchi	0·05	52·0	0·1
Ginbaso } *Sargassum*	Chiba	0·03	51·9	0·06
Kombu A. } *Laminaria*	Hokkaido	0·2	18·17	1·0
Kombu B. } *Laminaria*	Hokkaido	0·15	27·3	0·6
Kombu C. } *Laminaria*	Hokkaido	0·1	17·15	0·6
Kombu D. } *Laminaria*	Hokkaido	0·2	20·3	0·9
Laminaria angustata	Various places	0·23 (av.)	23·93 (av.)	0·99 (av.)
„ *longissima*[1]	Various places	0·24 (av.)	36·85 (av.)	0·63 (av.)
„ *japonica*	Ofudgun	0·14	22·27	0·62
„ *japonica*	Various places	0·26 (av.)	26·81 (av.)	0·92 (av.)
„ *religiosa*	Fukugama	0·16	24·16	0·68

[1] The identity of this species is doubtful (cf. p. 170). The only published record appears to be that of Miyabe (1902).

From this table it can be seen that Kajime and Arame have a greater quantity of iodine in their fresh weight than Kombu, but that after ashing the position is reversed and the Kombu yields more iodine. One would have thought that the amount of iodine in Ginbaso was scarcely sufficient to make it worth while processing.* Below we now give a table showing the range of iodine content in different brown European seaweeds, as found by various workers, together with the amount in the ash.

* Similar low values of iodine have been recorded by Scruti (1906) for species of *Sargassum* and *Cystoseira* in the Mediterranean. This worker found a distinct seasonal variation, the maximum iodine content in both genera occurring in April.

Seaweed	*Iodine as % of dry weight*	*Iodine as % of wet weight*	*% Ash in the weed*	*% Potash in the ash*	*% Iodine in the ash*	*Lb. iodine per ton of ash*
Fucus vesiculosus	0·02–0·03	0·003–0·103	6·4	14·9	0·04–0·2	3·9
(Bladder wrack)	0·12–0·38)[2]					
Fucus serratus	(0·04–0·177	0·007–0·067	5·6	17·6	0·2	4·9
(Black wrack)	(0·54)[2]					
Ascophyllum	0·04–0·86	0·009–0·23	6·2	12·9	0·23–0·4	
(Knobbed wrack)	(0·57)[2]					9·4
Laminaria saccharina[1]						
(Sugar wrack)						
Leaf	0·2–0·28	0·03–0·09	—	—	—	—
Stem	0·08–0·2	0·03–0·3	—	—	—	—
	(1·94–4·24)[2]					
Laminaria digitata						
(Sea girdles)						
Leaf	0·13–0·49	0·09–0·25	5·3	23·3[3]	1·36–1·7	38·0
Stem	0·17–0·63	0·12–0·44	6·1	29·9[3]	1·04–1·65	34·7
	(2·57–4·67)[2]					
Desmarestia aculeata	(2·4–4·65)[2]					
Laminaria cloustoni[1]						
(tangle)						
Leaf	0·09–0·42	0·07–0·1	4·7	19·9[3]	1·4–4·25	30·5
Stem	0·40–0·76	0·1–0·23	5·7	33·7[3]	1·0–2·96	23·4

[1] Data obtained by Freundler (1922) for these two species do not agree with those of other workers in that the values seem much too high. They are useful, however, in that they illustrate the variation in the iodine content during the course of a year and from different localities.

[2] Values reported by Trofimow (1934) for Russian material. They are so high compared with those of other workers that they must be regarded as suspect, but re-investigation may show that they are valid because other workers have found great differences in iodine content of seaweeds from different regions. See table at foot of next page.

[3] Laboratory samples.

Whilst the table shows that the oarweeds are very rich in iodine, there are other seaweeds as rich or richer, but unfortunately they do not occur in sufficient quantity to enable them to be used commercially, e.g. Dulse (*Rhodymenia*) contains 0·7 per cent iodine and *Traillieila intricata* 0·53 per cent.

From the last column in the same table it can be seen very clearly why the peasants liked the oarweeds (*Laminaria* species), because the amount of iodine per ton of ash was three to nine times as great as it was in the rockweeds. It can also be seen from a comparison of the second and last columns that although the percentage of iodine is greater in the wet stipes than in the wet blades of the *Laminaria* species, nevertheless the ash of the laminae gives a higher yield of iodine than that of the stipes. The proportion of stipe to lamina in a sample will therefore play a large part in determining the final yield of iodine. It is perhaps worth while to give some examples in order to show how the products may vary. Thus, in 1914, the amount of potash in kelp made in Western Scotland varied from 5·2 to 21·95 per cent, whilst the amount of iodine ranged from 0·1 to 1·14 per cent. Variations due to differences in locality (and perhaps also manufacture) may be illustrated by some figures for kelp prepared in 1915 from the Outer Hebrides.

	S. Uist	*Benbecula A*	*Benbecula B*	*N. Uist A*	*N. Uist B*
% Potash in ash	19·2	9·0	10·3	9·0	10·8
% Iodine in ash	1·14	0·58	0·6	0·4	0·4
Lb. of iodine per ton of ash	25·5	13·0	13·0	9·0	8·5

It has already been mentioned that the iodine salts are not uniformly distributed in the different parts of the plants, and that the amount in the living plant varies from month to month. The next table, giving the percentage of iodine in the ash from

		% *Iodine of the dry weight*			
		January (Roscoff)	*February (Roscoff)*	*February (Portrieux)*	*March (Portrieux)*
L. cloustoni	Stipe ..	0·81	0·55	0·66	0·66
	Frond ..	0·74	0·49–0·54	0·88	0·7–0·75
		March	*July*	*August*	*September*
L. saccharina	.. ..	0·6	0·71	0·76	0·46

the Japanese alga Kajime (*Ecklonia*), illustrates the effect of season, age and type of organ upon the amount contained.

Part of Plant	*Mar.*	*April*	*May*	*June*	*July*	*Aug.*	*Sept.*
Young stalk	0·13	0·14	0·21	—	—	—	0·39
Old stalk	0·25	0·26	0·3	0·5	0·5	0·35	0·59
Young leaf	0·13	0·13	0·19	—	—	—	0·29
Old leaf	0·21	0·26	0·17	0·6	0·72	0·26	0·53

This table shows that generally the iodine content is least in the young plant and highest in the old plant and that in the latter the iodine content reaches a maximum in July, which is the season of the year when the algae are principally gathered.

Recent work (Annual Report Scottish Seaweed Research Association, 1946) on the chemical composition of both littoral and bottom weeds has shown that in the former the ash, nitrogen and iodine contents are at a maximum during January and February. The ash and iodine content do not exhibit any marked variation, the former ranging between 14 and 24 per cent and the latter from 0·03 to 0·15 per cent of dry weight. The iodine content of "loch" weed is lower than that of "open sea" weed, a feature which is probably due to the lowered salinity of loch water. The nitrogen content of littoral weed varies considerably, maximum values of 1·4 to 2·4 per cent occurring in March as against minimum values of 0·14 to 1·1 per cent in the early winter months.

In the case of the sublittoral weeds the fluctuations are considerably greater. The curves for the ash and nitrogen contents (Fig. 17) more or less run parallel and show a maximum in the spring (*L. digitata* and *L. saccharina*) or in the early summer (*L. cloustoni*), whilst minimum values are reached in summer (*L. digitata, L. saccharina*) when photosynthesis is at its maximum, or in winter (*L. cloustoni*) when the metabolic processes are at their minimum. The variations are therefore not uniform and they suggest that the physiological processes of these different species may vary. The iodine content behaves somewhat similarly. The variations obtained are comparable with Freundler's results in that the frond usually contains more iodine than the stipe.

In Europe Cauer (1938) has published some data which show that the respective yield from the parent species and one of its varieties may be sufficiently divergent to be of economic significance. The failure of many of the earlier workers to distinguish the various varieties may therefore render their analyses of little value.

	% *Iodine in ash*
Laminaria digitata, leaf of young plant	1·45
,, ,, stem of young plant	1·65
L. digitata var. *flexicaulis*, leaf of old plant	0·54–0·61
,, ,, ,, stem of old plant	5·5

It is probable that the difference in age of the material also accounted for some of the variation in the iodine content. In any event it is clear that further analyses are desirable when more attention should be paid to the naming of the specimens, their age, locality, condition and season of collection.

These results are extended further in the 1948 report of the S.S.R.A., where it is also pointed out that the seasonal variations which occur in the composition of sublittoral weeds are due to variations in the frond where the bulk of the photosynthesis must occur.

As an example of the earlier confusions one may refer to Hendrick (1916), who described the distribution of both *Laminaria stenophylla* and *L. digitata*, stating that the former grows nearer the shore than the latter. As he did not apparently recognise *L. cloustoni*, it would seem that he has named the deeper-growing *L. cloustoni* as *L. digitata* and the shallow-water *L. digitata* he has called *L. stenophylla*. His determinations were in fact later criticised by Sauvageau (1918), who also apparently suspected an error. It is only fair to say that Hendrick's reply (1919) to this criticism was that he had taken the advice of a distinguished botanical colleague!

One final comparison must now be made and that is the relation between laboratory and commercially prepared kelp. For this purpose Hendrick (1916), who was responsible for the analyses of the commercially prepared kelp from the Outer Hebrides given in the table above, has also provided the following analyses of laboratory-prepared kelp.

		% *Potash*	% *Iodine*
Laminaria cloustoni kelp	frond	23·34	1·69
	stem	29·89	1·55
Laminaria digitata kelp	frond	19·9	1·36
(*stenophylla*)	stem	33·73	1·04

A comparison of the figures in this table and the table on p. 67 illustrates forcibly the difference between laboratory prepared and commercially prepared samples. It also provides a warning that industries based on laboratory analyses may not achieve all that is anticipated. The poor results obtained commercially by the Scottish kelp workers are summed up by Hendrick as follows: "Scottish kelp has always been a poor, primitive and badly organised industry. The kelp is produced in an inefficient and badly organised manner by a large number of small makers, the crofters and small farmers of the islands. It is very variable in quality and often very impure. The means of collecting and drying the seaweed are very crude and wasteful."

Iodine Escape. Before bringing this chapter to a conclusion there is one interesting feature that must be mentioned. The existence of the coastal kelp kilns with their wasteful methods of production might be expected to have some effect upon the amount of iodine in the atmosphere. However, it was not until 1938 that Cauer investigated the effect of the iodine industry upon the iodine *milieu* of Europe. In Brittany it lies far above that of other parts of the world; more iodine is found in the air, water and food plants here than elsewhere. This is directly attributable to the iodine that escapes into the air when the seaweed is burnt. Similarly, the greater quantity of iodine in the atmosphere, water and food plants of central Europe is regarded as due to the seaweed industries on the Atlantic coasts of the various countries, because 25–50 per cent of the iodine in the dry weed is lost to the atmosphere and some of it must be blown over central Europe by the westerly winds. In 1937 Brittany produced 90 tons of iodine which meant that 22–45 tons also escaped into the atmosphere.

Cauer estimated that Europe might produce about 320 tons of iodine in 1939 if Russian production on the Black Sea commenced. In that event 80–160 tons of iodine would enter the atmosphere and 75 per cent (60–120 tons) would be deposited over inner western and middle Europe. It is certain, however, that Cauer's figures for 1939 were too optimistic and it is unlikely that the large output of the last century will ever again be achieved. Should the industry cease Cauer believes that there will be less iodine in the air and water, and hence in food plants, which presumably absorb it in solution. Such a state of affairs might therefore eventually lead to an increase of goitre in central Europe.

Present Status of Kelp Industry. So far as the kelp industry is concerned to-day Japan must be regarded as the primary producer of iodine from seaweeds. Figures for the French industry (cf. p. 56) show that some manufacture still takes place there, but in other parts of Europe the trade has almost died out. There is, for example, good reason to believe that the industry ceased in the Outer Hebrides about 1933. Cauer (1939), however, states that 40 tons of kelp were produced in Scotland in 1937, in which case it presumably was made in the Orkneys. Inquiries have, however, failed to substantiate this statement. Hoffmann (1939) says that the production of iodine had ceased in Norway before the beginning of the second world war, the last year of manufacture being 1926 when 7½ tons were made. Cauer, on the other hand, suggests that in the region of Stavanger as much as 70 tons may have been made in 1937, though it is true that the figure is queried. There was a project to produce iodine from seaweeds in Spain, sufficient to cover that country's annual requirements of 50 tons, but there is no record that such an industry was ever started.

Iodine and potash were also produced on the Pacific coast of North America but their manufacture will be considered in detail in the next chapter. It is also perhaps worth mentioning that during the last war potash was made from *Macrocystis* and *Ecklonia* in Tasmania, but this appears to have been purely a war-time measure as there is no record of its continuation.

The "iodine-from-seaweed" industry would therefore seem to be approaching its end. On the other hand the existing mineral deposits will one day be exhausted, and unless new deposits are found or new means of making iodine discovered, it is likely that the kelp industry may ultimately have to be resuscitated. If such is the case it is to be hoped that those responsible will take note and avoid the mistakes of the past.

CHAPTER IV

THE AMERICAN PACIFIC COAST INDUSTRY

MENTION has already been made of the big areas on the Pacific coast of North America that are occupied by the giant kelps, especially the species *Macrocystis*, *Nereocystis* and *Alaria*. The chemical composition of these kelps was studied in 1902 by David Balch who foresaw their commercial possibilities. Unfortunately, like many another prophet, he never obtained any gain commensurate with his vision. A tardy recognition of his services in this field was, however, paid by Cameron in the Journal of the Franklin Institute of Philadelphia in 1915.

Origin of Industry. It was about 1910, when a controversy arose between merchants in America and the Kali Syndicate of Germany, who at that time more or less possessed a monopoly of potash, that America began to pay attention to these natural resources. This controversy was in fact sufficiently important to involve diplomatic exchanges between the two countries. There are certain mineral resources in America that could be used for the manufacture of potash, e.g. deposits of the mineral alunite and also the salt deposits of old lakes and inland seas, but it was soon pointed out that the kelps formed one of the richest natural sources of potash.*

As a result of all these developments the production of fertilisers and potash salts was commenced on a commercial scale in 1912. The possibilities in the kelp industry were naturally exploited by company promoters, and scientific papers written between 1913 and 1918 refer specifically to the fact that a number of the firms formed to exploit seaweeds largely existed to take money from the pockets of unsuspecting citizens.

One anonymous writer summed up the earlier position in 1918 as follows: "The giant kelp of the Pacific coast has provided a good deal of material for dreams and almost a hurricane of gossip." On the other hand, there is little doubt that money was available for investment in the industry, but American

* Two very important documents give details of the resources. The first is Senate Document 90 of the 62nd Congress and the second is Report 100 of the U.S. Dept. of Agriculture, Bureau of Soils.

industrialists were not certain what would happen after the war, as witness Meade (1917): "I know of some millions of dollars which would be invested in establishing a potash industry in this country if we could be sure Germany would be inclined to exact stiff terms from the U.S., or dictate that she should go hungry. The thing which keeps this money out of such an investment is the fear, not that we won't have potash from Stassfurt as heretofore but that we will have too much, and that the German producers will be so glad to get Yankee dollars to pay their war debts that they will offer us potash on the same old $40 basis." The $40 basis was presumably the price of potash before the controversy mentioned above took place.

Seaweeds Used. The three kelps which occur in sufficient quantity to be economically useful are *Macrocystis* (the "bladder kelp" or "brown kelp"), *Nereocystis* ("black kelp" or "sea otter's cabbage") and *Alaria fistulosa* ("stringy kelp"). The elk kelp or *Pelagophycus* contains a higher percentage of potash than the other three, but it is not sufficiently abundant to be worked by itself, though when it occurs it is collected with the others.

These algae often form what foresters would call "pure stands", that is areas of weed in which there is only one kind of seaweed. South of Point Sur in mid-California *Macrocystis* is the principal species, though there is often a fringe of *Pelagophycus* on the outside, because the latter favours rather deeper water. North of Point Sur *Macrocystis* and *Nereocystis* grow either in separate communities or else in intermingled patches. In Alaska there are considerable beds of stringy kelp (*Alaria*), often with *Nereocystis* growing outside. These beds form a wonderful sight when seen from close at hand, and they are sometimes so dense that it is impossible for a small boat to penetrate them.

Macrocystis grows best where there is a continued swell, whereas *Nereocystis* and *Alaria* thrive primarily in rapid tideways. In the case of the bladder kelp (*Macrocystis*) the largest plants are always found in positions that are exposed to heavy swell. When the plant grows in shallow water the fronds lack vigour and the beds are not profitable for harvesting.* The fact that the best growth occurs in exposed places necessarily renders their collection somewhat difficult. South of Point Sur the largest beds, or "groves", of *Macrocystis* occur at depths of 6–10 fathoms, and

* Recent work indicates that two different species are involved, one growing in deeper water and one in shallower water (cf. p. 17).

they may be two or more miles in length and 50–100 yards wide. In Magdalena Bay there is one colossal grove five miles long and one mile wide. *Macrocystis* is regarded as a particularly valuable plant because when the fronds are cut and removed new stipes arise from the base, just as in the "stooling" of wheat, whilst the severed ones die away. When this fact about the regeneration of *Macrocystis* was discovered it was suggested, in a first wave of optimistic enthusiasm, that three crops a year might be obtained from the beds: one journalist (Crossman, 1918) even suggested four to six cuttings in a year. Even three cuts would, however, have been too drastic and the beds would soon have disappeared. It is irresponsible statements such as these that enter the literature and become repeated, and then later lead persons to false conclusions and raise hopes foredoomed to failure. Actually the rate at which regeneration in *Macrocystis* takes place is largely dependent upon the temperature, and there is only one region where even two crops a year would be economically possible.

It will be remembered that *Nereocystis* is an annual, and as the large leafy part of *Alaria* is also produced anew each year, both these plants would have to be harvested after sporing had taken place, otherwise there might be no young plants to provide an abundant supply for the following season. North of Point Sur to Vancouver Island, July has been suggested as the earliest month for reaping, whilst farther north in Alaska August would be the earliest because development is somewhat later on account of the shorter growing season.

At one time it was suggested that for these two annuals a "closed season" would have to be instituted by law in order to ensure that the beds were not cut too soon. However, since no extensive cutting has ever been carried out in areas where these two species are most abundant, the necessity for such legislation has not yet arisen. In the case of *Macrocystis* a heavy mat of weed is to be found floating at the surface towards mid-winter. At this season growth is rapid and more than compensates for the wearing away by wave action. Later the rate of growth decreases and the mat becomes thinner. A new crop of leaves is then formed between April and June, but as the summer becomes hotter the kelp tends to decay and the beds become thinner again. There are thus two periods in the year when the beds are thick, and two periods when they are thin. The effect of warm water on the rate of decay of *Macrocystis* is striking, and if the temperature of the water rises much above 20°C. whole beds may

disappear entirely. Several beds did, in fact, disappear completely as a result of this in the warm summer of 1917.

Composition of Kelps. Before we consider the different methods of collecting these plants, the composition of the kelps may be examined from the point of view of the potash and iodine that they contain. It will be seen from the range of figures available that *Pelagophycus* is commercially slightly more profitable than *Macrocystis* and *Nereocystis*, whereas *Alaria* is definitely much less valuable. In view of the relative scarcity of *Pelagophycus* this information is not of any great importance.

Species		*% dry wt. Potash*	*% dry wt. Iodine*
Nereocystis	(av. content)	19·6	0·19
	(range)	6·6—31·6	0·13–0·3
Macrocystis	(av. content)	15·6	0·23
	(range)	3·2—27·65	0·14–0·27
Alaria	range	2·9—13·1	trace
Pelagophycus	(av.)	19·9	0·4

Analyses of the other Laminariaceae of the Pacific coast have shown that *Egregia* has a low iodine content (0·08 per cent) and compared with the giant kelps it is also poorer in potash (10 to 13 per cent). *Costaria* and *Agarum* have only a trace of iodine, but some of the species of *Laminaria* are rich in that element. Thus *Laminaria bullata*, according to analyses made by Turrentine (1912), contains 0·4 per cent iodine, and *L. andersoni* 0·6 per cent. These plants would not prove so easy to harvest by mechanical means nor are they so abundant as the giant kelps, and hence they have received no further attention.

The above analyses give no indication of possible differences between the fronds and stipes. This is of immediate interest because there is usually a high proportion of frond in the commercially harvested material. A few careful analyses carried out by Burd (1915) throw some light on this point (p. 77).

From the data it can be seen that the percentage of potash is considerably higher in the stipe, so that if potash is to be the principal product it would be desirable to harvest as much stipe as possible. In the case of iodine the reverse holds true and the frond is the more valuable. Although these differences in content are distinct the methods of harvesting so far used have rendered

Plant organ	*% of the air-dry material*	
	Potash	*Iodine*
Macrocystis frond, San Diego	10·71	0·22
„ Pacific Grove	12·55	0·14
stipe, San Diego	19·49	0·12
„ Pacific Grove	22·01	0·13
Nereocystis frond „ „	18·65	0·10
stipe „ „	26·37	0·07
Pelagophycus frond, San Diego	18·65	0·32
stipe „ „	29·52	0·13

it impracticable to separate out the two types of organ. It has also been found that there is a variation in potash content, though not of iodine, with age; thus, older plants commonly have a higher percentage of potash than younger ones.

Both Burd (1915) and Turrentine (1912) discovered that the proportions of the salts may vary with geographical position. For example, the amount of potash present, as potassium chloride, in the kelps of southern California (San Diego) is less than that of those obtained from farther north at Pacific Grove or Puget Sound. The average figures obtained by Turrentine were 29·4 per cent for northern kelps as against 21·6 per cent for southern kelps. In the case of the iodine content the position is reversed, the southern kelps possessing on an average 0·29 per cent as against 0·16 per cent of the dry weight of northern plants. Burd's figures, however, only show a difference in the iodine content for the frond of *Macrocystis* and not in the stipe. Parker and Lindemuth (1913) carried out similar analyses and arrived at the same conclusions in respect of the potash.

	North KCl	*South* KCl
Nereocystis	28·1%	32·7%
Macrocystis	23·0	20·8

These workers could not, however, find a significant difference in the iodine content of northern and southern kelps. In view of this conflicting evidence it would seem that further analyses of the iodine content should be made.

Harvesting of Kelps. We may now consider the various methods of harvesting that have been employed. At first the plants were gathered by men operating from flat-bottomed

scows and using sickles with which to cut the plants below the water. The cut plants were then either hauled aboard the scows or allowed to drift ashore. The Coronado Kelp Company improved on this somewhat primitive method by using a barge with a rotating knife affixed to the front end. No attempt, however, was made to collect the weed into the boat and it was allowed to drift ashore. Both these methods were wasteful, because, unless the bed was close to the land, much of the cut weed would come ashore at places where it could not be gathered, and some must have floated out to sea. There was also opposition to this method of operation because local resorts objected to the additional amount of weed that came ashore, and which, if not collected, soon became putrid and odoriferous! The cutting of the kelp beds was further opposed by those persons who thought that the spawning grounds of fish would thereby be destroyed. In order to make certain that such was not the case 1,000 tons of cut weed were carefully examined, and only 10 lb. of fish food were found in it and not a single fish egg. After this piece of research there were no further complaints from the fishermen! Another objection was that some people regarded these big kelp beds as forming natural breakwaters, and fears were expressed that if the beds were cut sections of the shore would be exposed to heavy wave action and damage might ensue. Whilst it is true that a heavy bed of seaweed assists in breaking up the full force of storm waves, it is extremely doubtful whether these fears have any foundation in fact. This is, however, a point upon which some further research is desirable.

An additional matter of some concern was the suggestion that weed floating loose in the water would rapidly lose its potash salts, and therefore be of less value. These fears proved to be groundless: experiments showed that driftweed less than 8–11 days old had not lost an appreciable amount of potash, and plants were rarely likely to be in the water for more than that length of time.

In order to overcome some of these objections an improved method of harvesting was worked out by the Pacific Kelp Mulch Company, and with further improvements was adopted by the Hercules Powder Company. The cutter consisted of a dumb barge or scow fitted with an endless belt at the front. This belt passed down into the water to a depth of about four feet, but could be pulled up for inspection or for travelling at speed (Plate 5). At the bottom, and in front of the belt under the water, was

the cutting device; this consisted of a number of knives with a sideways movement of about four inches working over fixed blades. As the weed was cut the forward motion of the boat floated the weed on to the endless belt and thus it was conveyed out of the water on to the scow. In spite of every precaution some weed was inevitably lost in the first part of its passage up the conveyor belt. At the top of the belt the weed fell into a chopper where it was cut up by more knives into lengths of about six inches. As the weed came out of this chopper it passed on to another conveyor belt which carried it to a transport barge lying alongside. When full the transport barge set off with the load of weed to the factory. The cutting barge was propelled through the water at the rate of about four knots by a launch pushing it at the stern.

The boat of the Pacific Kelp Mulch Company had a crew of four men, one on the propelling barge, one man watching the cutting and warding off any logs which otherwise might damage the knives, another on the loading of the transport boat and the fourth acting as an engine man. With this equipment and crew about 25 tons of fresh seaweed could be harvested hourly.

The collecting ships of the Hercules Powder Company (Plate 4) and the Lorned Manufacturing Company (Plate 5) were larger and more efficient: they employed six to nine men, and could collect up to 50 tons per hour whilst operating at a speed of nine knots. As these boats had their own means of locomotion a separate propelling launch was not necessary. Hoffmann (1939) has calculated that one of these large boats must have collected about 700 tons of weed per day. This calculation, however, is apparently based on the assumption that only one boat was operating, whereas according to statements in the literature the Hercules Powder Company had more than one cutter. At the rate of 50 tons per hour, a single vessel would require a fourteen-hour day in order to collect 700 tons, and such long working hours seem scarcely likely.

By arranging the cutting knives at 4–6 feet below the surface it was calculated that about 50 per cent by weight of each *Macrocystis* plant was cut. In the case of *Nereocystis* it is probable that rather more than this porportion would be cut. If the knives were lower still the increase in yield was not raised to any great extent whereas the costs were increased considerably. The expense of the harvesting operation is one of the major items in estimating cost of production, especially when it is realised that about ten tons of green kelp are required in order to produce one

ton of dried weed. It was therefore important to evolve a machine that would cut considerable quantities of seaweed very rapidly, and at the same time harvest a substantial proportion of the crop available.

At one time a suggestion was put forward that a boat with a crane and a grab might be used to collect the weed. This, however, was rejected on the grounds that it would be very slow and cumbersome, and, more important still in the case of *Macrocystis*, it would tend to pull up complete plants, so that no holdfasts would be left from which regeneration could take place.

In the early stages of the industry when the kelp arrived at the wharf it was unloaded by means of a crane and grab, which had a capacity of about 30 tons per hour. Later, however, the Hercules Powder Company worked out a method whereby the kelp was macerated almost to a pulp in a second chopper before being passed to the transport barge. Then, on arrival at the wharf, sea water was pumped into the barge and the resulting "slush" pumped out along pipe lines to the factory.

Good weather is not normally encountered in these regions throughout the whole of the year, and as these harvesting boats were obviously somewhat unwieldy fairly calm weather was an essential requisite. August and September normally provide the calmest weather on the Pacific coast of North America, and are also the months most suitable for harvesting, because an earlier start might ruin the beds of the annuals, *Nereocystis* and *Alaria*. At other times of the year the groves are subject to gales, which may cause considerable damage. South of Point Sur bad gales only occur about once every three to four years, but farther north there are severe gales each winter, and it is essential to harvest the crop before these set in.

When, at the end of the 1914–18 war, the results of the cutting operations were analysed, it was realised that the policy adopted with regard to the actual cutting operations was of considerable importance. There are two possible ways of harvesting. The beds can either be cut systematically, as in cutting a hayfield or a corn crop, or else only the better parts of the bed can be cut. The latter is a wasteful process and naturally leads to intense competition among the different firms for the best beds or portions thereof. When the good areas have been cut the harvesting of the remaining thin beds is a wasteful process. If the cutting is systematically carried out over a whole bed, however, the loss in value and time due to the thin portions is com-

pensated by the better areas. The Hercules Powder Company probably evolved the best technique. They employed three boats, steaming one behind the other, rather like reaping machines in a large cornfield. Not only was the bed cut systematically but the second and third boats picked up some of the debris from the boat in front.

Costs. When the cost of these operations was being estimated in 1912–13 it was anticipated that there would be about 200 working days in the south and about 100 in the Puget Sound area. In 200 days a machine, such as that of the Pacific Kelp Mulch Company, should collect about 15,000 tons, the actual cost of the *dry* kelp being estimated at $4.95 per short ton (2,000 lb.).

In 1916 Laucks calculated that in Puget Sound, with a harvester employing two men and capable of cutting 100 tons in six hours, the cost of *wet* kelp would be 43 cents per ton. The Pacific Kelp Mulch Company estimated that their *wet* weed cost them only 20 cents per ton, whilst Higgins (1918), who had the advantage of writing after all these machines had been in operation for several years, concluded that it cost $1.10 to collect one ton of wet kelp. This figure is probably the most accurate and may be compared with the same author's value of $85 for one ton of pure potash produced.

In the early days there was some considerable argument as to whether any profit could be made by the industry. Thus Knudsen in 1912 estimated the cost of production per ton of potash as $40.90 and the income as $39.96, thus showing a loss of 94 cents a ton. These calculations were reviewed by Cameron (1912) who calculated the costs as $5.90 and the income as $22.12 per ton, with a profit of $16.22. Experience shows that it is extremely difficult to estimate costs of this nature in advance, and it is probable that the truth lay somewhere between the two. Somewhat later Burd (1915) came to the conclusion that "6·2 tons of *Macrocystis* must be harvested to give one ton of kelp (ash or dry) worth $12. Where this can be done at a profit the utilisation of kelp will be commercial success." So far as the Pacific coast is concerned it would seem that the drying and ashing processes are the expensive items.

It was further calculated that in order to supply the total potash requirements of the United States of America about a million tons of wet kelp would be required annually, so that there were undoubtedly prospects for a major industry. The

estimates of the available weed, about which some information is given later (cf. p. 243), showed that there was more than sufficient to meet this need: it was said that there was enough kelp to produce two and a quarter million tons of potash! This figure is, however, an exaggeration, but even so there is no doubt that the potential amount of potash and iodine available is very considerable. It is equally clear that in the past somewhat roseate views have been taken of the potentialities of this source of raw material.

From information given by Tressler (1923) it is possible to estimate the amount of potash actually produced from the algae. In 1917, 3,572 tons were obtained from nearly 395,000 tons of wet weed, and in 1918, 4,804 tons from 390,000 tons of wet weed. These were relatively poor results for the amounts of seaweed treated, and the output was not nearly sufficient to satisfy the demand. These figures implied a yield of 10–11 tons of potash per 1,000 tons of wet weed, but from the available analyses the yield of potash should have been about 15–16 tons per 1,000 tons of wet kelp. One can only conclude that the method of extraction was inefficient, though it must be remembered that other important products had to be obtained. However, as Hoffmann (1939) has pointed out, even if this result is compared with the potash production in Japan, where it is carried out chiefly by the old ashing method (cf. p. 64), the values are low: for example, it is reported that Japan produced 8,438 tons of potash in 1917. Indeed, the story of the Pacific coast industry is largely one of undue optimism combined with hopes that could not be substantiated by the methods of treatment employed.

A number of firms were formed to exploit these algae and by 1917 there were twelve companies in operation. Some projects never went beyond the paper stage, but among those that erected plants was the American Potash Company. They proposed to calcine the weed but the venture was not successful at the then price of potash. The promoters said that the failure was due to lack of capital which prevented them from building a plant of economic size. This firm was taken over by the American Products Company, who built an enormous barge which unfortunately turned out to be a failure. Their principal product was to have been a cellulose insulating compound for pliers and knife handles. The Hercules Powder Company, the Pacific Kelp Mulch Company and the Lorned Manufacturing Company were more successful. Swift and Company, a firm of meat packers, also

operated with some success. This last concern only required the potash for fertiliser products, and for this purpose they simply used the dried weed, collecting about 200 tons of wet kelp *per diem.*

Processing the Weed. Once the weed had been collected there were four methods of dealing with it:

1. It could be used directly in the dry state as a fertiliser.
2. After burning the ash could be used for the preparation of potash and iodine.
3. The dried weed could undergo destructive distillation in order to obtain the carbon and inorganic salts.
4. A fermentation process could be employed for the purpose of preparing acetone.

By 1915 the majority of the American workers had come to the conclusion that the first method, ignoring the iodine and other by-products, was the most economic. Turrentine, however, who had considerable experience in this industry, considered that the potash production could be carried on satisfactorily so long as all the by-products were extracted and sold. Burd (1915) also came to the conclusion that there were no great technical difficulties involved in the preparation of high-grade potash and iodine but that no big profits could be expected.

If the kelp is to be used in the dry state directly as a fertiliser it is important that the drying should take place rapidly, because that reduces what is known as the efflorescence. By the efflorescence is meant the evaporation of water from the surface of the seaweed so that a crystalline deposit of salts, principally salts of potash, is left behind. When the algae are ground up all these valuable salts become lost, because unfortunately effloresced salts cannot be utilised to advantage in the commercial preparation of potash, if a large yield of a high-grade product is required.

On the Pacific coast the earliest attempts at incineration were similar to those in Europe, i.e. the weed was dried and burnt on the beach and the product sold to the fertiliser companies, the price being based on the potash content.

The indefatigable David Balch (1909) took out a patent for treating these kelps by heat, but it does not appear to have been used to any extent. Under this patent the weed was to be charred at 200°C., when it yielded a product which was called "saline humus" that could be used as a fertiliser.

The Lorned Manufacturing Company of California then developed a more modern and less wasteful method of handling the seaweed. The kelp was first of all chopped up and sent to a 200-ton storage bin. From here the chopped weed was fed as required into two revolving driers, which were so arranged that the weed passed backwards and forwards from one to the other. The bulk of the moisture was removed in these driers, but even so about 25 per cent still remained. The kelp contains so much water that 1,500 tons required 38,000 gallons of oil fuel in order to dry them. The expense of the drying process is probably one of the more important items contributing to the cost of this treatment. At this stage, however, the weed was dry enough to be burnt and was sent to the incinerator, which was a rotating horizontal kiln with oil flames shooting down it. After incineration was complete a grey charcoal was left, which contained on an average about 36 per cent potash. No by-products were obtained from this process, and therefore it was only a commercial success so long as the price of potash was high.

There existed, however, a considerable belief in the efficiency of the destructive distillation process, if all the by-products were used, and therefore the United States Bureau of Soils erected an experimental kelp potash plant at Summerland, in California, which worked from August 1917 to the spring of 1921 under the direction of Dr. Turrentine. This factory was designed to treat 100 tons of wet kelp every 24 hours. The kelp was first of all chopped up, and then passed along two revolving horizontal air driers through which air was forced in the opposite direction to that in which the kelp was travelling. These air driers, as in the case of those of the Lorned Company, were heated by means of oil burners. The weed when it came out of the driers was packed into vertical fireclay retorts (closed vessels with one exit), which were then heated to a temperature of 800°C. Experiments showed that a high temperature was essential, because at low temperatures, e.g. 320°C., the products were not satisfactory. The volatile products which came off were condensed for further treatment: there were two groups of these and they were dealt with separately. There was a heavy tarry substance which was redistilled in order to obtain light oils, heavy oils and pitch. A lighter ammonia liquor also condensed and on distillation gave ammonia. Unfortunately these kelp distillates, according to Hoagland (1915), were not commercially valuable, and in this respect at least the Americans were no more successful than Stanford (cf. p. 59). There were

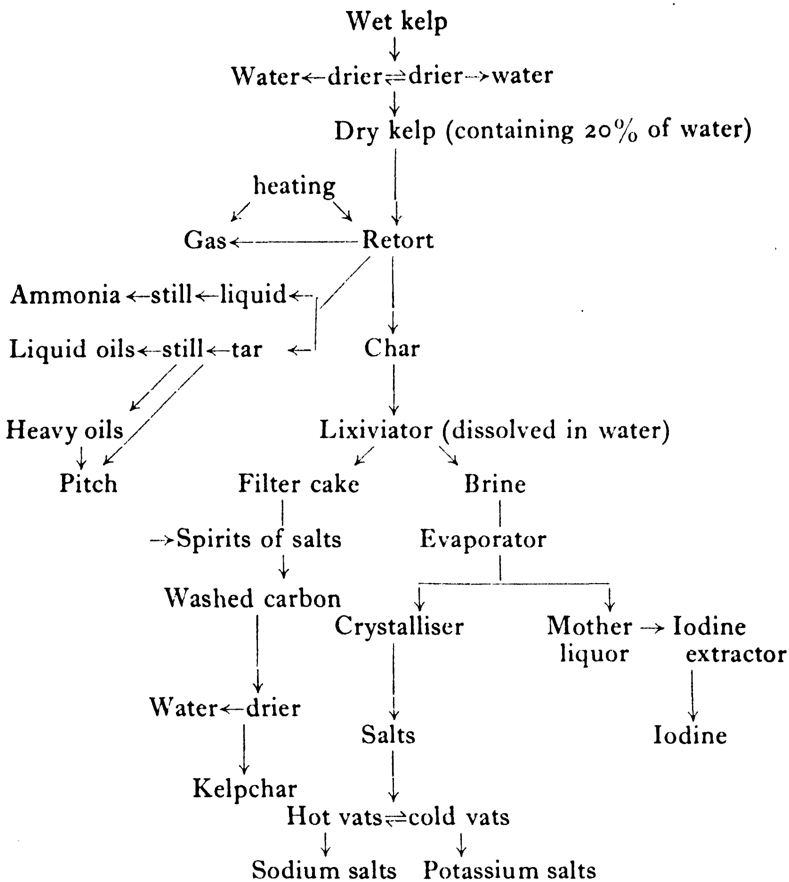
in addition some gaseous products, but these were led back to be used in the heating of the retort.

At the finish of the distillation process, a charred mass was left in the retort. When it had cooled it was removed, broken up and dissolved in hot water. A strongly saline solution resulted, and after filtration the brine was evaporated down so that the sodium and potassium salts crystallised out. From the mother liquor iodine could be extracted by means of a suitable treatment. The sodium and potassium salts were separated from each other by alternate crystallisations in hot and cold vats; the sodium salts crystallised out in the hot vats and the potassium salts in the cold. It is interesting to note that although these seaweeds grow in salt water, which contains a very high proportion of common salt or sodium chloride, nevertheless much of the salt in the alga is in the form of potassium chloride, which is not so abundant in sea water. These seaweeds, therefore, have the power of extracting and accumulating the potassium salt from the surrounding medium.

The filter cake from the dissolving or lixiviating process was extracted further by means of spirits of salt (hydrochloric acid), and then washed in a counter-current of water and dried. This product was known as "kelpchar" and was extremely efficient as a decolouring and deodorising carbon, because it was so highly absorbent. It was later shown by Zerban and Freeland (1918) that the method of preparation of the kelpchar played an important part in determining its decolorising properties. Kelpchar has been suggested as a suitable decolorising agent in the manufacture of sugar, and preliminary trials showed it to be as efficient as other agents.

In the destructive distillation process described above, 100 tons of *Macrocystis* would yield on an average 12 tons of dried kelp, which on further treatment gave 2·3 tons of gas, 3·3 tons of ammonia, 2·1 tons of tar, 3 tons of potash salts, 1·2 tons of kelpchar and 20 lb. of iodine. According to the average analyses for *Macrocystis* given earlier (p. 76), the yield of potash was high, but there should have been nearly three times as much iodine. The disadvantage of this process was the high cost of obtaining by-products, which could not then be sold at competitive prices, and as it could only be profitable if all the by-products were obtained and utilised it was not particularly successful.

An outline of the process, as used in California, is given in the scheme below:



There is still the fourth or fermentation process to be considered. The purpose of this technique was to extract for use and sale the organic material which forms more than half the dry weight of the kelps. In this way it was hoped to reduce still further the cost of production. Alcohol, for example, can be obtained from seaweed if some of the organic material is to be used. In this case, according to Kayser (1918), the algae are first of all macerated and then decomposed by treating them with a dilute acid. Next they are boiled in an autoclave at a temperature of 120°C., after which some organic nitrogen and yeast are added. Lillig (1934) mentions that experiments have shown that 100 kilograms of absolutely dry seaweed yield about 21 litres of alcohol. By slightly varying the process lactic acid can be

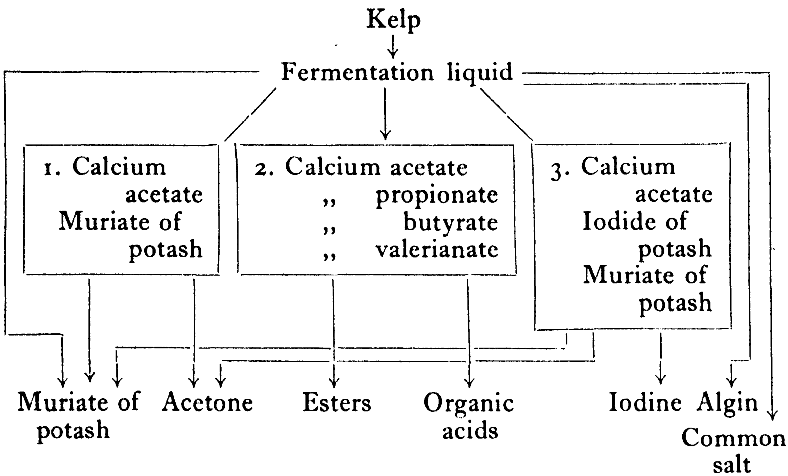
obtained instead of alcohol. However, the profit on this method of production is very small, and as a result no practical use has been made of the process.

In the 1914–18 war there was a serious lack of acetone, and so the Hercules Powder Company, of Los Angeles, set out to obtain acetone from kelp with potash as a by-product: this was a large undertaking, and as the acetone was produced for war aims regardless of cost, it was closed down at the end of the war because it could not run profitably in peacetime. The plant, which was erected at San Diego, utilised in this process 24,000 tons of wet kelp per month, or 1,200 tons per working day. The daily intake yielded 13 tons of 95 per cent potassium chloride as against an expected 16 tons, and 1,575 litres of acetone (Crossman, 1918). An account has already been given of how this company macerated the kelp before transferring it to the transport barge. On arrival at the wharf the kelp "soup" was pumped directly into the fermentation tanks, where it was diluted and allowed to ferment for two to three weeks. This apparently caused a considerable stench, because Crossman (1918) says: "There came galloping out to meet us, before we got even to the outpost, a smell that would cause women to faint and strong men to hesitate. It didn't smell like anything else in the world, but once smelled it is never forgotten." Some idea of the size of the plant at San Diego may be gauged from the fact that there were 156 tanks, each containing 50,000 gallons of fermenting liquid. The factory employed 1,100 employees and in the last thirty months of the 1914–18 war it used 621,000 tons of wet kelp.

The organic acids liberated in the fermentation process were neutralised by the addition of carbonate of lime (chalk), and the liquid was then passed through screens for filtration. Next it was concentrated by evaporation, and during this process three fractions crystallised out and were dealt with separately. The scum which formed was known by the workers as "taffy" (presumably a corruption of toffee) because it was plastic whilst hot.

The first fraction to crystallise out contained calcium acetate and muriate of potash. This was heated in a retort in order to obtain the acetone. The second fraction was treated with sulphuric acid and alcohol in order to secure derivatives of acetone. The third fraction consisted almost entirely of iodide of potassium and was treated with chlorine in order to obtain the iodine, which was subsequently dried and purified. Muriate

of potash and common salt were also formed as by-products, and although no details of their separation are given it probably took place after the evaporation process. Algin was the only other major by-product, and it was left behind in the fermentation mass after it had been screened. Some idea of the process can be obtained from the scheme below (Higgins, 1918*a*).



From the foregoing account it should be clear that there is a vast supply of weed in the Pacific. In the past it would seem that the best methods have not been used and the results have therefore been disappointing, and it was perhaps unfortunate that some of the work was carried out during years when conditions were abnormal. A fair summary of the position would seem to be that given by Allen (1923): "Technology without economics is doomed to failure. No stable market can be expected until the products of a plant are of standard grade and quality, and until a steady supply is available with no reason to expect the discontinuance of operations."

CHAPTER V

AGAR-AGAR

Agar. Two things are commonly called by the name of agar-agar. On the one hand it is the well-known name of a trade product in Europe, which is prepared from certain species of red algae, but on the other hand it is also used on occasion for drugs prepared from untreated red algae which have merely been dried. There is no doubt that much confusion exists in the use of the term and likewise there is also much erroneous information about its sources. The word is of Malayan origin and in that language it refers to red seaweeds of the genus *Eucheuma.* Hoffmann (1939) states that the word agar in Malay referred to the red alga *Gracilaria lichenoides*, but this statement is not correct as *Eucheuma* is the genus most widely used in Malaya for making agar.

It is evident that the application of the word agar requires to be standardised, and its use should be restricted to the dried extract. It has been suggested by Tseng (1944*a*) that the term "agarophyte" should be applied to the seaweeds used for its manufacture. A critical definition of agar is not possible at present, because in the sequence it will be shown that it is prepared from a number of different red algae and therefore its composition must vary. A tentative definition (modified from an earlier attempt) has been put forward by Tseng (1945*a*) as follows: the dried amorphous, gelatin-like, non-nitrogenous extract from *Gelidium* and other agarophytes, being the sulphuric acid ester of a linear galactan, insoluble in cold but soluble in hot water, a one per cent solution of which sets at 35° to 50°C. to a firm gel, melting at 80° to 100°C.

Sources of Agar. The untreated drugs are differentiated according to the country of origin. Hence there is Ceylon agar or Ceylon moss. This affords an example of the use of the word agar as applied to untreated red algae, a usage which should be abandoned. It has led people to believe that agar in its true sense used to be produced in Ceylon, whereas there is no evidence that such was the case. At present even the production of the untreated alga has ceased. Ceylon moss refers to the

dried red seaweed *Gracilaria lichenoides* obtained primarily in the island, though it also grows on the coasts bordering the Indian Ocean, where it is called Bengal isinglass. Chinese moss refers to another species of *Gracilaria*, *G. confervoides*. Macassar agar, Java agar, algal-algal, or East Indian carragheen, comes from the Malay archipelago, where the principal source is the red seaweed *Eucheuma muricatum* f. *depauperata* (= *E. spinosum* or

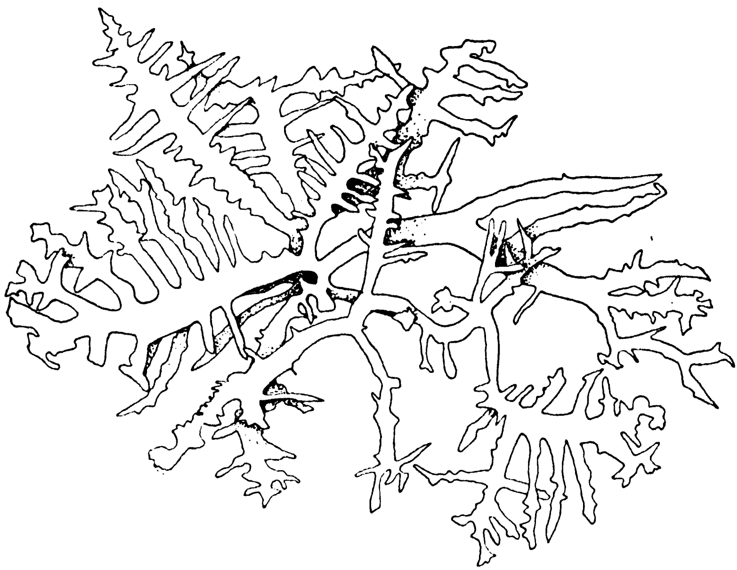


FIG. 18. *Eucheuma serra* (× 0.6) (After Yamada)

E. denticulatum in some of the literature) though other species of *Eucheuma* may also be employed. The various islands in the archipelago use different names for the algae employed in the production of agar. Thus in Bali *Eucheuma serra* (Fig. 18) is known as "boeleong lelipan", *E. muricatum* in Luigga is called "agar-agar", in Galipoeda just simply "agar"; in the island of Ceram the same species is known as "agar-geser", whilst in Spermonde it is known as "agar-poeloe".

When any of the species mentioned above are boiled they yield a gelatinous material, which sets to a jelly on cooling. These gels can be used in exactly the same way as the agar prepared in Japan. A considerable quantity of this East Indian agar is, in fact, exported to Japan, where it is used to adulterate their own

purer product. It has also been exported from Indonesia to China for over a century and is known on the Chinese markets as "Chilints'ai" ("unicorn vegetable") (Tseng, 1944 *a*).

In Japan agar-agar goes under the name of "Kanten", which means "cold sky", and as such refers to the fact that the material used to be prepared on cold winter days, or else high up on the mountains where it is always cold. Since the second world war a number of other countries have embarked upon the manufacture of agar, and various genera of red algae have been used, e.g. *Gelidium* (U.S.A.), *Gigartina* (England), *Pterocladia* (New Zealand), *Suhria* (South Africa), *Ahnfeldtia* (Russia).

From the above account it will be realised that agar is not derived from even a single algal genus, and it may therefore be expected to be diverse in its characters and properties. It is very important, therefore, that in all investigations concerning this material, and in chemical analyses, the exact species and even variety should be clearly stated. There is little doubt that much of the older information about agar is rendered useless because no attention has been paid to this matter of proper identification.

Agar Industry in Japan. For many years Japan has been the principal producer of agar* and it is therefore convenient to describe the industry in that country first. It is said to have been introduced into Japan from China in 1662, and, according to Horiuchi (Tseng, 1944*a*), the following dates have all been suggested for the discovery of the present method of agar manufacture, involving freezing and thawing: 1647, 1655, 1658 and 1688. In these early days the product had no connection with the word agar and as late as 1893 it was still called dried seaweed jelly, though it had been known to European scientists for some thirty years.

We may first note that there are other names by which the important Japanese product is known, e.g. Oriental or Japanese isinglass, Japanese gelatine, gelose, Hai Thao or just simply Thao. It is not always possible to obtain a clear picture as to which algae are used in Japan for agar-agar. This is partly because the species are extremely difficult to distinguish, and partly because the different species have the same common name among the populace. As a result a very confusing synonymy has arisen, which is not readily disentangled. It would

* Tressler's (1923) statement that the agar of commerce comes from Japan, China, Malaysia and Ceylon is not correct because none of these regions except Japan produced appreciable quantities for export.

appear, however, that *Gelidium amansii* is the most important plant. Davidson (1906) uses the specific name *swansii* which is probably a misprint for *amansii*. In Japan this particular species is called "Tokoro-tengusa", "Kinukusa" or simply "Tengusa" (Fig. 11*a*). The last name, however, would seem rather to refer to the genus *Gelidium* as a whole and not properly to this species: *Gelidium pusillum*, for example, is known as "Hai-tengusa". According to Takamatsu (1938) *G. amansii* is known in some of the islands as "Makusa".

Earlier authors were probably uncertain of the identification of the species and incorrect names were undoubtedly given. Thus Marchand (1879) reports that *Gelidium polycladum* (= *G. pacificum*) is the principal species in Japanese isinglass, whilst Holmes (1904) stated that the Thao of Japan refers to *Gelidium spinosum*, but as there is no such species it is probable that he meant *Eucheuma spinosum* (*E. muricatum* f. *depauperatum*). Recent Japanese literature does not support either of these statements. Smith (1904), Tressler (1923), Newton (1945) and others considered that the most important alga used for agar in Japan was identical with the European species *G. corneum*. There is no evidence that this species occurs in Japan, though it is probable that *G. crinale*, which does occur, may have been mistaken for it.

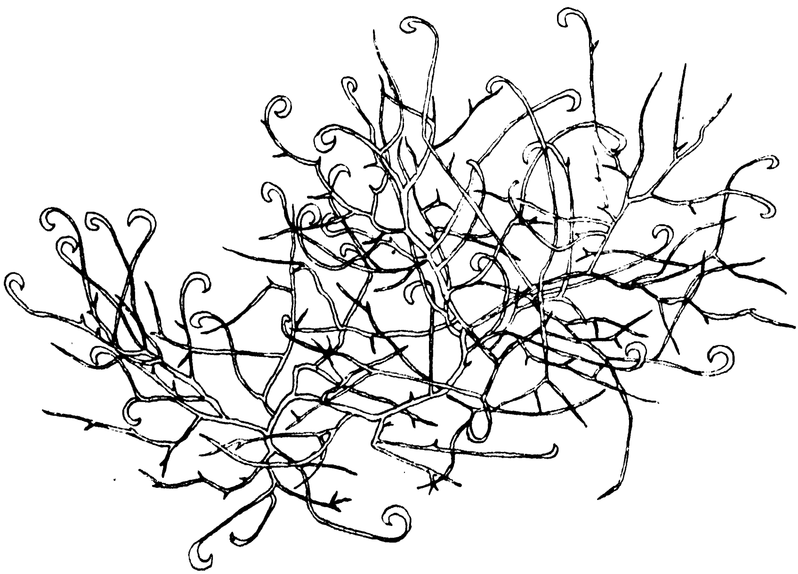


FIG. 19. *Campylaeophora hypneoides* (× 0.9) (After Okamura)

In the past the specific name *corneum* was used on occasions when the species had not been clearly identified, and this fact has contributed to the confusion.

"Kinukusa" (*G. amansii*) gives a very good yield because 25–30 per cent of the dry weight is composed of the gelatinous material, although plants from another red genus, *Acanthopeltis japonica* ("Tora-ashi" or "Yuikiai"), are of much the same value and yield a first-grade agar. There are a number of other species which yield an inferior product so that they can only be used when mixed with a good-quality agar. These species, most of which are exported from Formosa, include *Gelidium subcostatum* or "Hira-kusa", *G. japonica* or "Onigusa", *G. pacificum*, *Campylaephora hypneoides* or "Yego-nori". (Fig. 19), *Pterocladia capillacea* and *Gracilaria confervoides* ("Ogo-nori").

In 1903 there were 500 factories manufacturing "Kanten" in Japan with the principal centres of production in Hokkaido and at Osaka, Kyoto, Hyogo and Nagano, together with the prefectures of Schizuoka, Miye and Wakayama (Fig. 20). Tseng (1944*a*) states that it is now produced principally in the prefectures of Osaka, Kyoto, Hyogo, Nagano, Yamanashi and Gifu, using the original method described below. More agar is also produced in Karafuto (Sakhalien) using a different source and another method of preparation (cf. p. 99).

When the manufacture was first commenced, agar was simply a mass of jelly obtained by boiling seaweed, but now it appears on the market in the form of sticks, sheets and bars, a manner of preparation which was taken up quite accidentally, due to the fact that one day some jelly was put out of doors and solidified in these shapes. The story is that one day, about 1658, the Emperor was marooned in a snowstorm and took refuge in an hotel where some seaweed jelly was prepared for him by the innkeeper Tarozaemon Minoya. The remainder was thrown outside and evidently froze during the night. The next morning the frozen jelly thawed and turned into a dry papery translucent substance, which the innkeeper discovered could be reconverted back into jelly.

The seaweeds are gathered in Japan from the rocks between mid- and low-tide marks, or else divers collect them from the sublittoral regions. The best months for collection are July and August, though harvesting actually takes place continuously from May to October. After the weed has been collected it is dried on the shore and is partly bleached. It is then sold to the factories, where it is stored until the arrival of the cold winter

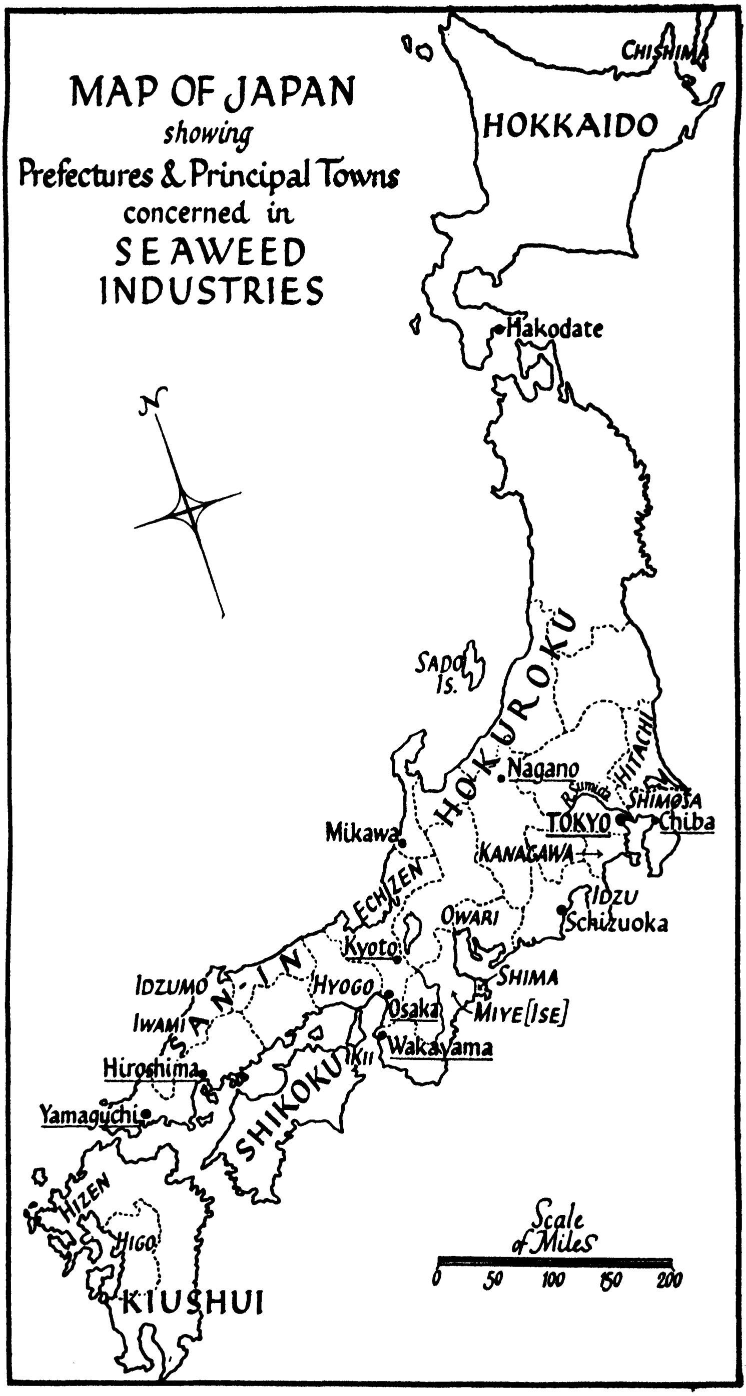


FIG. 20. Map of Japan showing prefectures and principal towns concerned in seaweed industries.

months, though nowadays with refrigeration this is not necessary.

The stages in the further treatment are as follows: it is first of all cleaned by beating and pounding, whilst larger lumps of foreign material are picked out by hand. Finally it is washed in running fresh water, after which it is laid out to bleach on mats. This is done in warm weather, beginning in August, and the bleaching is much aided by dew. If the conditions are very favourable twenty-four hours may be sufficient for the process, but it usually takes several days. The importance of blanching for ordinary commercial use is exaggerated because it is not really necessary: it is, however, desirable for bacteriological purposes. As the drying and bleaching goes on the algae fuse into thick or thin sheets which can be loosely rolled. Later on in the winter these sheets are put into large wooden or iron vats together with some water, the exact quantity depending on the state of the weather and the condition of the seaweed (Fig. 21*a*). It is boiled and stirred for 5–6 hours, after which a weak acid is added and the boiling continued for another half-hour. The boiling extracts the gelatinous principal from the seaweed and it is strained off through a coarse cloth into a vat. This is followed by a more thorough straining with a fine linen cloth in a press operated by means of a lever (Fig. 21*b*). The waste seaweed material is collected and boiled again, whilst a peculiar rectangular wooden vessel, seen in the picture (Fig. 22), is used to dip out the jelly and pour it into the wooden trays to cool, either in the open air or nowadays in refrigerated rooms. This jellied material is known as "Tokoroten".

A freezing temperature is now essential for the next stage, but, before being subjected to the freezing process, it is cut up by means of oblong iron frames with sharpened edges into suitable sizes for further handling (Fig. 23); in this state it is known as bar kanten or "Kaku Kanten". When the bar kanten thaws after being frozen, the water flows away with the impurities, leaving behind relatively pure agar-agar, which is dried in the sun. The freezing process, either in the open or in refrigerated rooms, takes from one to three days and another three or four days are allowed for drying. It is rather interesting to note that Holland imports only the bar kanten which is largely used by the Dutch in the manufacture of beer.

The kaku kanten is also put into cylinders and pressed out through a perforated base into thin fine threads 30–35 cm. long, looking rather like macaroni. This material is known as "Huoso"

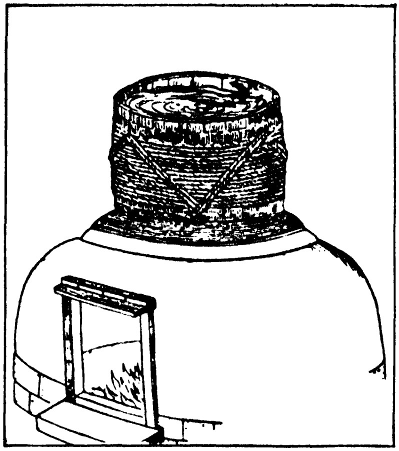


FIG. 21(*a*). Furnace and tub for the boiling of *Gelidium*

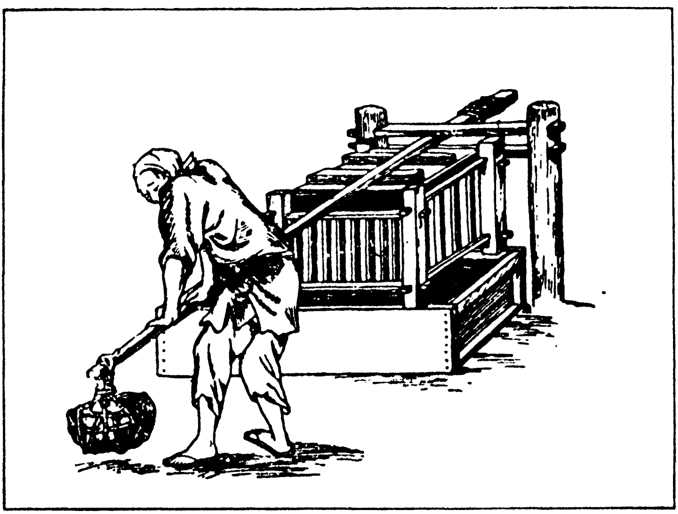


FIG. 21(*b*). Press for straining crude seaweed jelly

(From Japanese prints after H. M. Smith)

or "Hoso Kanten". The kanten is finally parcelled up and made into bales weighing 133 lb., but it is sometimes sold in a shredded or powdered form. The commercial product is pearly

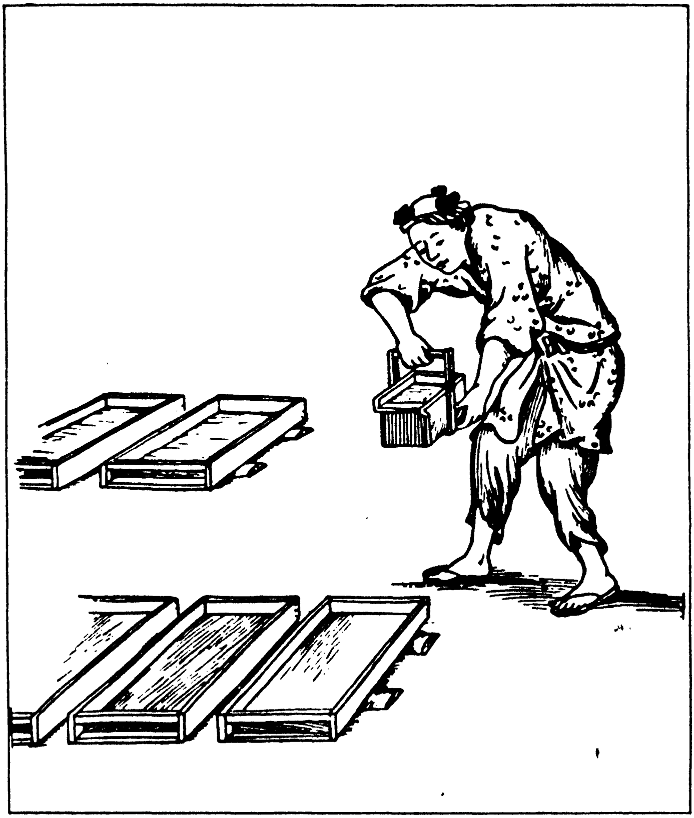


FIG. 22. Pouring liquid Kanten into cooling trays

(From Japanese print after H. M. Smith)

white, shining and semi-transparent, and is also tasteless and odourless.

Davidson (1906) explains why the site for the freezing of the tokoroten must be carefully selected. The locality most suited to the operation is one that is bounded on the north-west by mountains or hills, and by meadows on the south-east. If the mountains are to the west the sun sets sooner, congealing commences early, and there is no rapid change to the required

cold temperatures, and as a result the colour of the kanten is spoilt. When the mountains are in the north they intercept the cold north winds and cause them to deposit their rain, and then a cold dry wind blows over the meadows. The meadows are required for laying out the kanten, because no sand or dust is then likely to become admixed during the freezing process.

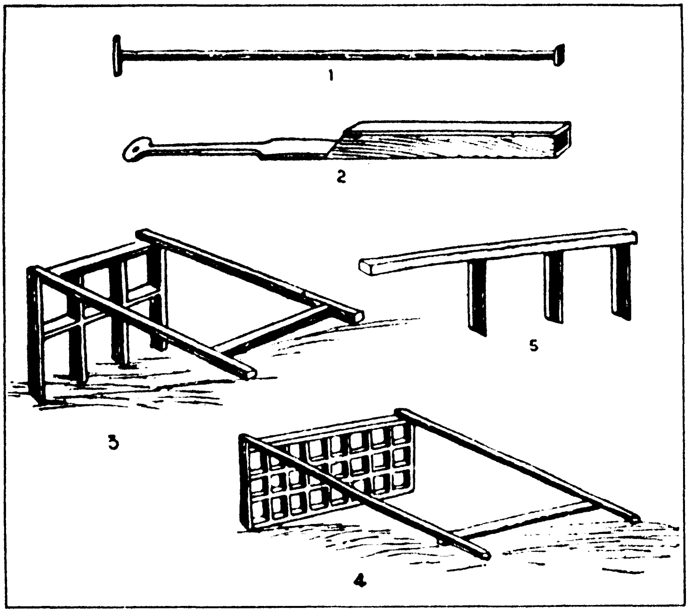


FIG. 23. Articles used in cutting seaweed jelly into sticks and bars. (From Japanese print after H. M. Smith)

The final product is not always a pure kanten produced from a single species of *Gelidium*. It has already been mentioned that the Japanese import agar from the Malayan region, which they use for adulterating their own product. The amount of adulteration varies from 20 to 40 per cent, the exact quantity depending on the purpose for which the agar is required. Marchand (1879) was even able to identify thirteen different species of algae in one particular sample sent to Europe.

The words of Professor Tondo (1923) may aptly be quoted in summing up the process of manufacture. He says: "The success of the preparation of kanten depends a great deal on atmospheric conditions. Although the source is simple the process

is complicated and demands great experience. It is necessary to take great care in the choice of materials and their mixing; the situation of the locality or how it was gathered, the nature of the ground, the kind of climate and the quality of the water are of the greatest importance. Moreover, the selection of the workers, their application and patience are some factors equally important; the Japanese bring to this work their artistic taste, which is consummate and varied."

The output from Japan is very considerable as the following figures show:

1902 (max. output to this date)	1,000 tons Kanten
1923–31	1,340 ,, annually
1923–37	2,450 ,, ,,
1936	2,549 ,, Kanten from 12,000 tons raw seaweed.
1938–40	Output reduced, 2000 metric tons (Newton, 1949).

In 1936 Horiuchi states that there were 512 factories in operation, and the total value of the output was worth about £480,000. It is significant in the light of subsequent events to note that in 1938 Germany was the largest single purchaser. In the pre-war years, America imported about 300 tons, Great Britain 300 tons, Australia 70 and New Zealand 15 tons from Japan. The actual figures of imports of Japanese agar for 1938 are as follows: Germany, 266 tons; France, 200 tons; England, 131·5 tons; Dutch East Indies, 72·5 tons; Australia, 64·5 tons; and the Straits Settlements, 26 tons.

Japan not only leads the world in the production of agar, but also in its consumption. Thus, in 1902, 164 tons or 16·4 per cent of total production were consumed internally (Tseng, 1944*a*), whilst in 1936, 943·5 tons or 37·6 per cent of an increased production were consumed internally.

It will be remembered that mention was made of a different process for the extraction of agar in Sakhalien (p. 93). Sakhalien agar is manufactured from an entirely different red seaweed, *Ahnfeldtia plicata*, which has since been used as a source by both the Russians and the British. The use of this alga is relatively recent because it was first employed about forty years ago (Tseng, 1945*a*). At the present time Russia is the principal producer of agar from this source, where a factory for the purpose has been erected on the shores of the White Sea.

Although the process of agar manufacture came to Japan from

China, the industry in the parent country declined considerably, and in later years China was importing considerable quantities from Japan. In 1906 73 per cent of the total Japanese export went to China and Hong Kong, but in 1938, because of the Sino–Japanese War the imports had been reduced to about 49 tons. Prior to 1937 China did possess a small agar industry of her own with three factories at Ningpo, Tsingtao and Chefoo. It has been estimated by Tseng (1944*a*) that their annual production was about 75,000 lb. (cf. also addendum, p. 250).

Agar Industry in America. We may now consider the production of agar in countries other than Japan. In 1920 it was decided to ascertain whether agar-agar could not be produced in America, because it was stated that "even if the cost of local production surpassed the price of the imported material, it would be important as a measure of national security to develop all domestic resources". This surely showed commendable foresight! A number of the species of red seaweed growing on the Californian coast were likely to be suitable and so an industry was established at San Diego.

By a strange turn of fate, the person who laid the foundation of the now flourishing U.S. industry was a Japanese, Chokichi Matsuoka. He built his factory at Tropica (now Glendale) in California. Tseng (1944*b*) has pointed out that Matsuoka in his first patent emphasised the use of a red alga *Gloiopeltis*, and only casually mentioned *Gelidium* as a substitute. The former alga does not grow to any extent in California and has never been used as a source of agar in any country. It is evident that Matsuoka employed *Gelidium*, but, presumably in order to mislead possible competitors, he purposely emphasised *Gloiopeltis* in the specification of the patent.

According to Johnstone and Feeney (1944) this first concern discontinued operations in 1934, but a more accurate and detailed history is given by Tseng (1945*b*). In 1923 Matsuoka's concern was purchased by a company headed by John Becker, and this engineer modernised the whole process in the course of the next few years. He took out a number of patents covering a special combined congealer and sizer, a de-waterer for flaked agar and a special dehydrater. This process is still that employed to-day in the United States.

This new company was unable to weather the last depression and finally closed in 1933. In that year a former employee of the company established the United States Agar Company in

National City, California, and between 1934–38 reprocessed Japanese agar since this material was so cheap. This small company became the nucleus of the present American Agar and Chemical Company of San Diego, a firm which now obtains most of its raw material from Mexico and Laguna, San Pedro, and Redondo in Southern California. In 1942, when the U.S.A. issued an agar freezing order, this factory had a monthly output of about 4,000 lb., but in 1945 there were five concerns for the production of agar though not all were in production. Tseng (1944*a*) estimates that the expected annual output in California will ultimately be about 100 tons. South of the border it is reported (Tseng, 1945*b*) that two factories have been established in Mexico.

Because of the war shortage* scientists and industrialists on the Atlantic seaboard of the United States also became interested in the production of agar. Investigations by Humm (1942) showed that *Gracilaria confervoides* was present in commercial quantities near Beaufort, N.C. In 1944 three factories were in existence on the Atlantic Coast and experiments were in progress with a view to utilising yet another red alga, *Hypnea musciformis* (De Loach *et al.*, 1945). The work was later extended to Florida (Humm, 1947) where two species, *Gracilaria blodgettii* and *G. foliifera*, were found to be abundant, but these two species only yielded an inferior product which can best be termed an agaroid.

On the Pacific coast the principal species used is *Gelidium cartilagineum*,† which in extreme cases may grow to 4 feet tall, but is usually 3 feet. It is regarded as harvestable when it reaches 18 inches. It is found in commercially harvestable quantities only in southern California: here it occurs in small concentrations where the tidal current is strong. Additional species that have also been employed are *G. nudifrons*, *G. arborescens* and *G. densum*. This last species was apparently used by Matsuoka at Glendale (Gardiner, 1927). There is no dearth of red algae of the agarophyte class in California, and species that could be used, if localities are found where they grow in commercially harvestable quantities, are *G. pyramidale* (previously referred to as *G. amansii* but now shown to differ from the Japanese species), *G. pulchrum* (=*G. australe*), species of *Gigartina*, *Gracilaria confervoides* and *Endocladia muricata*.

* In 1947 America had commenced re-importation of agar from Japan.

† Tressler (1923) and Hoffmann (1939) state that *G. corneum* was one of the principal species employed. This species is not now regarded as occurring on the Pacific coast, and it is probable that *G. cartilagineum* was the species really involved.

The importance of *Gelidium cartilagineum* in the production of agar has naturally directed the attention of scientists to problems connected with its survival, and also to a study of seasonal changes in the amount of gelling material. A prime necessity is to discover whether the methods and times of harvesting will have any detrimental effect upon the future supplies of the seaweed. In this connection Johnstone and Feeney (1944) have shown that there is no seasonal periodicity in reproduction, and that therefore time of harvesting is not of particular importance. It has also been found that regeneration of cut plants and maximum vegetative activity both occur chiefly in spring and autumn.

In an attempt to provide an answer to the second problem, Cooper and Johnstone (1944) have studied the seasonal production of the agar material in *Gelidium cartilagineum*, and they have found that there is a peak production in June with a general summer maximum (May to July). Their figures also show that the length of time of boiling in the production process may affect to a considerable extent the quantity of material extracted.

	Weight of dry agar	
Month	*Boiled 2 hours*	*Boiled 4 hours*
January	3·89 grs.	7·11 grs.
February	1·98 ,,	6·86 ,,
March	3·54 ,,	7·91 ,,
April	6·26 ,,	7·37 ,,
May	6·88 ,,	9·94 ,,
June	7·40 ,,	11·30 ,,
July	5·17 ,,	7·86 ,,
August	4·26 ,,	5·82 ,,
September	5·79 ,,	8·23 ,,
October	3·24 ,,	6·97 ,,
November	5·38 ,,	8·13 ,,
December	5·34 ,,	7·15 ,,

The peak production is associated with the period of maximum photosynthesis, and it is therefore suggested that the price should be determined by the season of harvesting. In view, however, of the wide fluctuations, especially after four hours' boiling, this would hardly seem feasible.

In California harvesting is carried out by divers who collect the plant by hand. Each boat has a crew of three—diver, boat operator, and life-line tender. The alga is put into a rope basket which is hauled to the surface when full (it then contains 60–70 lb. of seaweed). In a single working day a diver

can harvest up to $1\frac{1}{2}$ tons of fresh *Gelidium*, but quantities less than this are more normal. Diving can only be carried out when the water is calm and without a strong ground swell. Because of this most of the collecting is restricted to the period between May and November. Some companies furnish the boat and facilities and pay the harvesters $85 per fresh ton, whilst in other cases the harvesters provide the boat and equipment. In the latter case they also dry and bale the weed. Under these conditions the harvesters receive $350 to $400 per ton of sun-dried seaweed.

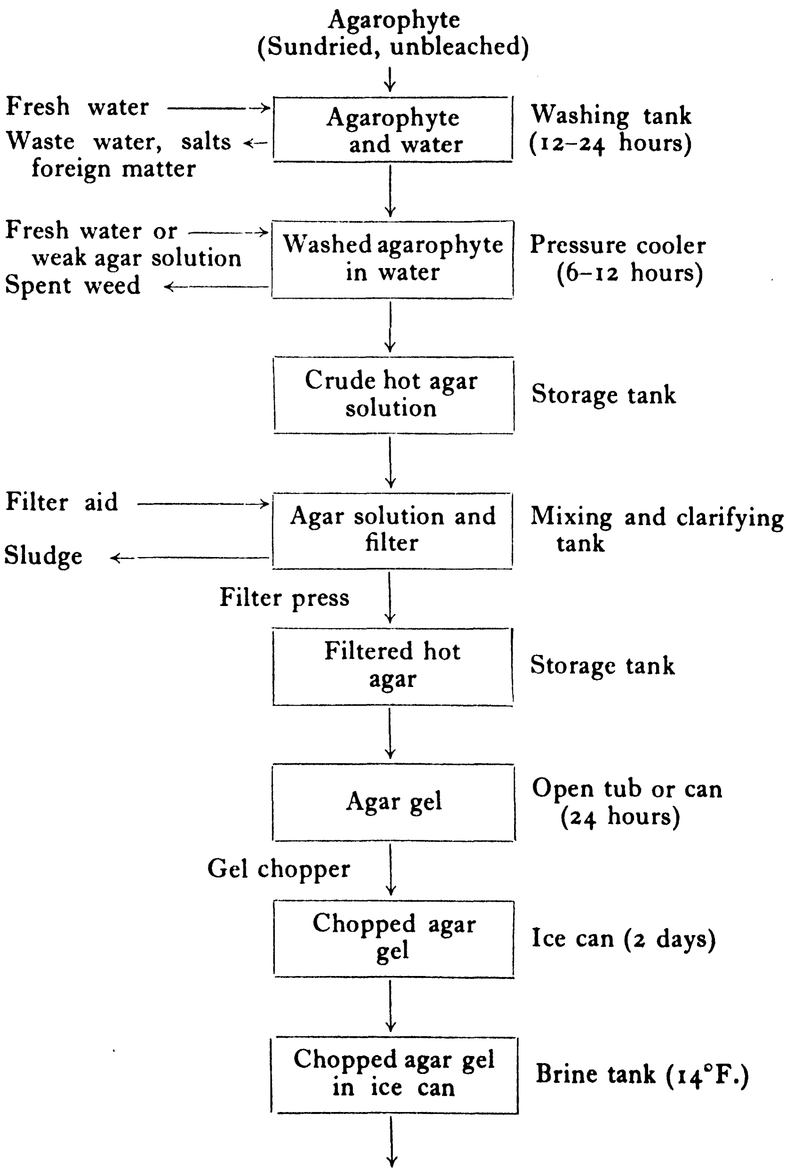
The preparation of agar from these seaweeds follows much the same lines as the Japanese process, except that the equipment is more up to date and a refrigerated room is used for the freezing stage. If species of *Gigartina* are used, a preliminary soaking is first of all necessary followed by a boiling in a solution containing 2 per cent chloride of lime. Unless this is carried out the resulting jelly is not firm enough for commercial purposes. Matsuoka not only introduced artificial freezing, but he also substituted bleaching by chlorine for sun bleaching. The value of this method of bleaching is open to some doubt because of possible effects upon the gel strength.

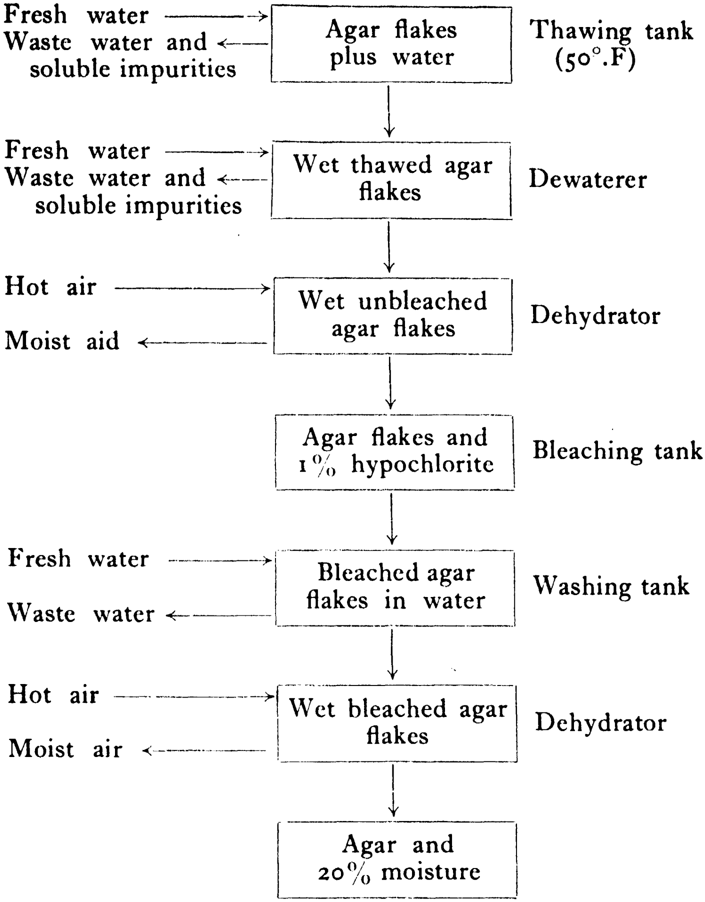
The *Gelidium* is first washed and soaked for 12–14 hours, after which it is transferred to pressure cookers, where it is cooked for 6 hours at a pressure of 15 lb. to the square inch in a dilute agar solution from the third and final cook. It then receives two more cookings before being discarded. The extract is clarified and filtered, and then poured into open tubes where it gels after 24 hours. The gel is chopped up and put in cans in the freezing-rooms at 14°F. for about two days. On removal it is thawed and placed in the dewaterer which removes the washing water with the soluble impurities.

The purified agar flakes, which now contain about 90 per cent moisture, are dried by hot air until they contain about 35 per cent moisture. After this they are bleached in 1 per cent sodium hypochlorite solution at room temperature. The excess bleaching reagent is reduced by sodium sulphite, after which the agar is removed, washed, and finally dried until only about 20 per cent moisture remains.

In the original Becker process there was a special combined congealer and sizer, which was used to cool and gel the solution. This has now been abandoned in favour of the older method of cooling and gelling in open tubs. Also in the original process activated carbon was used to decolorise the agar. Unless great

care was taken particles of carbon passed into the final product, and so the function of the carbon has been replaced by the bleaching process.





Flow diagram of the American process of agar manufacture as used in California. The bleaching portion is used by only one firm (After Tseng, 1945 *b*).

Work on the agar seaweeds at La Jolla (Tshudy and Sargent, 1943) has shown that the pH of the extracting solution is of very considerable importance, but the effect varies for the different species. Thus the yield from *Gelidium cartilagineum* and *Pterocladia* species is maximal around pH 6–8 and falls off with increasing alkalinity. In the case of *Endocladia muricata* the reverse holds true, the maximum yield being secured at pH 12. Attempts by these workers to extract agar from *Gigartina canaliculata* and *G. serrata* were only successful when they adopted

the treatment, used by Kizevetter (1937), to secure agar from *Ahnfeldtia plicata* on the maritime coast of Russia and from *Phyllophora rubens* in the Black Sea.

On the east coast of America an agar industry using *Gracilaria* has been making rapid headway. In the first nine months of 1944, 25,000 lb. were produced, whilst prior to that period, from August 1943 to January 1944, approximately 50,000 lb. of agar had been produced (Humm, 1944). Collection commences about August 1st and continues until mid-November, when it ceases, so that the remaining *Gracilaria* can serve as a "stock" from which the succeeding year's crop is developed.*

The plant grows in shallow waters, which are more or less protected against wave action, and it exists in two forms, a free-living sterile phase and an attached fruiting phase. The former increases solely by vegetative means and the latter by the normal sexual and asexual processes. It is possible that these two phases are completely distinct, in the same way as the free-living marsh fucoids of European salt-marshes are distinct from the attached parent species. It has been found that low temperatures and insufficient light may retard or even inhibit growth (Causey *et al.*, 1945). Thus the most rapid development takes place at sea temperatures between 25° to 28°C., whilst the light intensities that are found at depths of 2–4 feet permit of the most rapid growth.

Because of its habitat the *Gracilaria* is readily harvested by forking the seaweed into small boats, by accumulating it in "stop nets" placed at right angles to the tidal current, or by trawling in deeper waters. After collection it is air-dried, the process taking three to four days. Three tons of fresh *Gelidium* yield one ton of dry weed, but according to De Loach *et al.* (1945) it requires 10 tons of wet *Gracilaria* to give one ton of dry weed. Tseng (1945*b*) on the other hand reports seven tons of wet weed as giving one ton of dry weed. In Australia it will be seen later (p. 113) that 7–8 tons are required to give one ton of dry weed. Seven tons are therefore probably the minimum, and in general it is likely to be rather more.

Extraction must take place under steam pressure or by boiling, and it would seem that although the extraction is easier than that of *Gelidium* the amount extracted is not so great. Not only does the agar content vary with the season, but so must the method of extraction. Thus material collected between June and early

* Recently attempts have been made to transplant *Gracilaria* from N. Carolina to Miami, in order to start the industry in Florida.

August can be extracted satisfactorily without attention to the acidity (pH) of the extracting solution. For material collected later in the year the pH of the extracting solution must be adjusted to a point below 6·5 (i.e., it must be distinctly acid) as may be seen from the data below (samples 5–8).

Variation in yield of Gracilaria confervoides.

Sample	*Date of collection*	*Yield %*	*pH*
1	June 20th	21	7·3
2	July 3rd	37	7·3
3	August 1st	40	7·3
4	„ 15th	11	7·3
5	„ 31st	1·3	7·3
6	„ 31st	30	0·1% acetic added
7	October 4th	1·6	7·3
8	„ 4th	38	0·1% acetic added

Monthly Yield of Gracilaria

Month	*No. of samples*	*Yield: % dry weight.*
July	3	38
August	6	34
September	9	32
October	10	29
November	4	18

The total agar content of North Carolina *Gracilaria* lies between 55 and 65 per cent on a dry weight basis, and although 25–35 per cent can be obtained in the laboratory such yields are not likely with commercial equipment. One factor which tends to bring about this result is the presence in the late autumn of an adulterant, the red alga *Laurencia poitei*. An extract of this alga when heated brings about partial hydrolysis of the *Gracilaria* agar, and this introduces filtration difficulties, so that the full yield is not obtained.

Evidence has also been secured which shows (Stoloff, 1943) that *Gracilaria* agar is a complex of several gelling materials, and in this respect it is similar to the extract from Irish moss (cf. p. 155). The gel strength of this *Gracilaria* agar compares favourably with that of *Gelidium* agar and it can be increased 5–15 per cent by the addition of potassium chloride (cf. p. 249).

Experiments have also been carried out with another red alga in North Carolina with a view to using it as a source of agar (De Loach *et al.*, 1945*b*). The alga is *Hypnea musciformis*, which thrives along the entire Atlantic coast of North America. The plant is easily collected from shallow bays between mid-

May and mid-July. It should be washed after collection and then air-dried. In order to obtain an extractive that will gel, the seaweed must be extracted as for *Gracilaria* but with 0·2–0·5 per cent potassium chloride in the water and the pH adjusted to about 6·0. The gel strength and temperature of gelation are related to the concentration and kind of solute present, but in general potassium chloride is the most suitable substance for

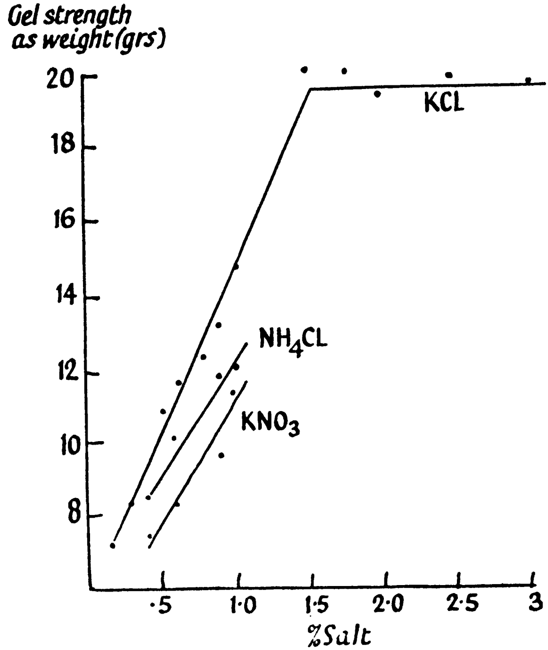


FIG. 24. Effect of adding different salts in varying concentrations on the gel strength of *Hypnea* extract (After Humm)

control of these properties (Fig. 24). Thus a 1 per cent solution of the *Hypnea* extractive plus 0·5 per cent potassium chloride yields a gel of greater strength than the agar from either *Gelidium* or *Gracilaria*. The strength of the gel can be further increased by adding more KCl up to an optimum concentration of 1·5 per cent. From these facts it would seem that the *Hypnea* extractive, with the control that can be exerted over it, may prove to be a very valuable substance indeed. As in the case of the *Gracilaria* agar, the *Hypnea* extractive apparently consists of a number of different fractions.

This brief survey of the American agar industry may fittingly

be concluded with the production figures so far as they are known (Chase 1942; Tseng 1945*b*).

1923	..	7,755 lb.	1934	..	1,802 lb.
1924	..	7,281 „	1935	..	8,061 „
1925	..	117,773 „	1936	..	—
1926	..	29,877 „	1937	..	21,208 „
1927	..	—	1938	..	7,170 „
1928	..	22,797 „	1939	..	8,098 „
1929	..	5,140 „	1940	..	24,000 „
1930	..	44,895 „	1941	..	52,000 „
1931	..	28,395 „	1942	..	110,054 „
1932	..	10,009 „	1943	..	165,954 „
1933	..	41,557 „	1944	..	113,762 „ (Jan.–Aug. only)

From these figures it will be observed that there was a considerable drop in production in 1934 after the principal agar company closed down. A statement by Ferguson-Wood (1942) that just prior to the second world war (1938) America was producing 6,000,000 lb. annually cannot be regarded as correct. It is possible that this figure should have been 6,000 or else it included production from the Irish moss industry (cf. p. 157).

Agar Industry in Russia. In recent years Russia has also entered the agar industry and about ten years ago factories were built at Archangel, Vladivostock and Vladimir. These three centres produced a total output of 54·5 tons in 1936 (Kizevetter, 1937), all derived from the red seaweed *Ahnfeldtia plicata*. In the same year a factory at Odessa produced 200 tons of an inferior product, known as agaroid, from *Phyllophora nervosa*,* which grows in quantity in the Black Sea (cf. p. 63). Tseng (1944*a*) considers that this material is probably more closely allied to carragheenin (cf. p. 155) than to agar, but subsequent investigation may show it is an agar substance.

Agar Industry in Great Britain. When Japan entered the last war the principal source of agar supplies immediately became cut off. Since agar is of very considerable importance in bacteriological work (cf. p. 120) every country conserved its stocks with great care, and research was immediately put into train in order to provide agar from local seaweeds. In Great Britain it was found that species of *Gelidium*, though occurring on her coasts, are not present in commercially usable quantities. In Ireland agar has been manufactured from *Gelidium pulchellum* and *G.*

* Newton (1949) gives *P. rubens* as the species but according to De Toni (1897) this species does not occur in the Black Sea.

latifolium (Plate 11*a*), since these two species occur in sufficient quantity to be harvested (Yarham, 1944). In England it was found that a suitable agar could be produced from *Chondrus crispus* (Irish moss) and *Gigartina stellata*. Both these species occur in considerable abundance, and Prof. Newton not only organised a survey of the available supplies but later arranged for their collection. Agar production was commenced in 1943 when 10 cwt. was manufactured, whilst in 1944 the output was greater as 40 tons of dry weed were collected.* Orr† reports that the agar differs from that of the Japanese in having a higher ash content and a lower melting point, but on the other hand it dissolves more readily and yields a clearer gel. As in the case of *Gracilaria* and *Hypnea* agar the melting and gelling temperatures are both affected by the presence of electrolytes. Small quan-

* Ministry of Supply data. † Personal communication.

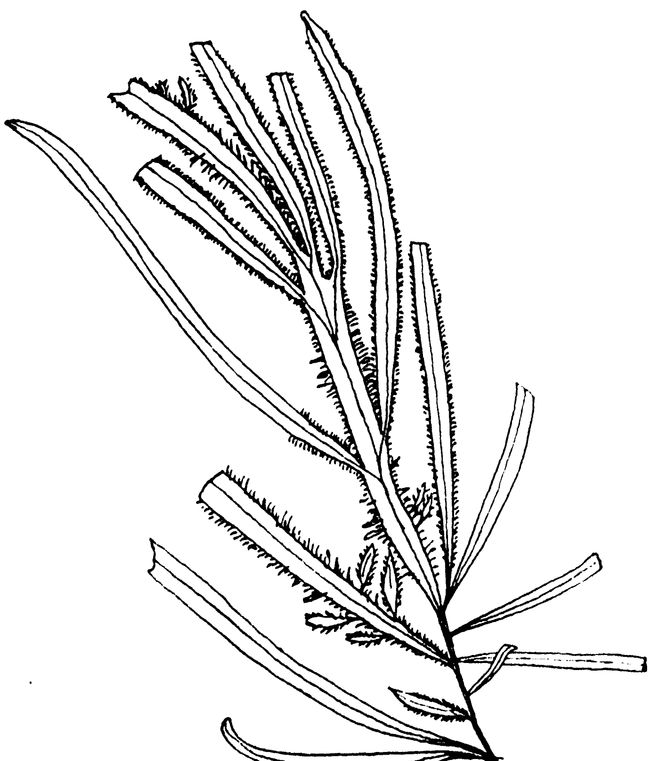


FIG. 25. *Suhria vittata* (× 1/3) (After Isaac)

tities of a very good agar were also manufactured from *Ahnfeldtia*, but this alga is not very abundant in Great Britain and so could not be employed on a commercial scale (see addendum, p. 249).

Agar Industry in South Africa. In South Africa a number of seaweeds would appear to be suitable for the manufacture of agar-agar, though the quality of the product varies with the species. The most satisfactory species appears to be *Suhria vittata*, or "red ribbons" (Fig. 25), which also has a culinary use. The local name refers to the fact that it looks like a bunch of narrow red ribbons with a delicate fringe along both edges. The gelatinous material is apparently very easy to extract from this species. The species that is commonly used, because it occurs in quantity, is *Gracilaria confervoides*, or "sea string"

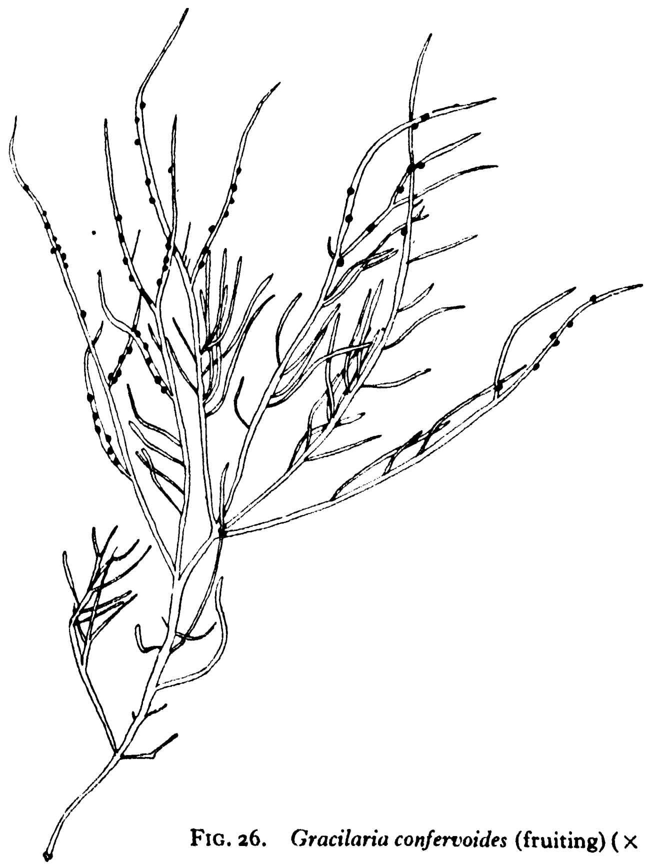


FIG. 26. *Gracilaria confervoides* (fruiting) (× 0.7)

(Fig. 26), which grows below low-tide mark on the Atlantic side of the Cape. The best plants are found where there is sheltered water and the bottom is sandy or sand with rocks. Big meadows occur in at least two localities and much of the weed is cast ashore after the winter storms. The agar produced from this seaweed serves extremely well in the manufacture of sweets. *Gelidium cartilagineum*, or "red lace", grows in bunches hanging down from the rocks near low-tide mark where it looks like "jabots of crimson-red lace". This gives a good yield of agar, but only when it is extracted under pressure. A related species, *G. pristoides*, or "brown sea parsley", is also common and abundant from mid- to low-tide marks. This species provides as good a source of agar as "red ribbons" (*Suhria*) and is just as easily processed. *Hypnea spicifera*, or "green tips" (Fig. 27), gives an abundance of jelly, but when attempts are made to convert the jelly to dried agar strips by freezing it tends to break down and become watery. In view of the experiments upon *Hypnea musciformis* in the U.S.A., it is likely that this difficulty could be overcome by the addition of electrolytes. There is thus quite a variety of seaweeds that can be used in South Africa, and now that the industry has been started it would be in the national interests for it to be retained.

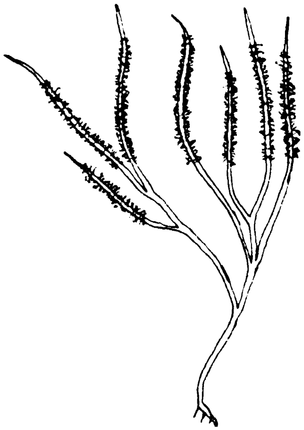


FIG. 27. *Hypnea spicifera* (× 1/3)

Agar Industry in Australia. Australia has not been behindhand in her efforts to produce agar. In the last century a company was formed at Dongarra in Western Australia for the purpose of making agar from the red seaweed *Eucheuma speciosum*. Now, however, agar is being made in New South Wales from *Gracilaria confervoides*,* which is very abundant in Botany Bay, of Captain Cook fame. It has been estimated that there is enough of this red seaweed in New South Wales, where it grows down to depths of 20 fathoms, to produce 100 tons of agar annually. This would seem to be sufficient for Australian home

* Recorded in error by Ferguson Wood (1942) as *E. spinosum*, and as *Gracilaria furcellata*.

needs as she consumed only 71 tons in 1938. Apparently Australia, and wisely too, intends to continue the industry because attempts are being made at present to cultivate the *Gracilaria*. Ferguson Wood (1942) reports that there are great variations in the quantities available and so a periodical examination of each estuary will be necessary. Even if the *Gracilaria* is not harvested it still disappears from the beds at the end of the season. This is exactly comparable to its behaviour in North Carolina, and, so long as harvesting stops in sufficient time to leave a "stock" for the next year, there should not be any great decrease in the source of supplies. It has been suggested that fences should be built along the shore near low-water mark in order to catch the weed coming ashore, when the plants break off, and so prevent it being buried by the sand. The species is distributed along a coastline of 850 miles.

A special grapnel has been devised for its collection, and this would appear to be the only case of a special trawl designed to collect these smaller seaweeds. The basic structure is the Agassiz trawl, so named after a famous American zoologist. A two-inch mesh net is used so that the sand can be washed out whilst collecting, a process also facilitated by trawling against the tide. A glass buoy is attached to the net as a direction indicator and also as a salvage line should the two ropes break. The Australians have found that the best results are obtained by using a motor-boat with a 7 h.p. engine with a towing rate of a quarter speed. This type of equipment works satisfactorily in 6–100 feet of water, which is probably as deep as one would require. In order to give some idea of its efficiency, it can be stated that hauls made in Botany Bay during the course of one hour produced 600 lb. of wet weed, whilst in another bay three hauls, occupying half an hour in all, brought in a harvest of 400 lb.

When the boats return to harbour, the weed is laid out on wire-netting racks to dry. Sometimes it is dried by artificial heat, but in such cases the product is not so good. When dry it is treated in the same way as in America, by boiling with steam in open vats, and great care has to be taken to control the acidity of the solution. It has also been found that the use of iron and copper vessels tends to make the agar discoloured. Ferguson Wood (1942) gives some further details of the industry in Australia: thus, it takes 7 tons of wet drained *Gracilaria* to produce one ton of dry dark weed, but 8 tons of wet weed are necessary in order to produce one ton of bleached weed. Fer-

guson Wood does not, however, believe that bleaching is really necessary. One ton of agar can then be produced by boiling 3 tons of the dark dried seaweed (therefore 21 tons of wet weed yield one ton of agar), and the product is said to be not inferior to imported Japanese agar. Some idea of the labour involved can be gauged from the fact that it is estimated that twenty men can harvest, dry and bleach 8 tons of wet weed per day.

Western Australia is apparently still manufacturing agar from *Eucheuma*, but the collection of this seaweed is more difficult. The available amounts of this alga are not well known, and it is intended to institute surveys in order to obtain the necessary information.

Agar Industry in New Zealand. Moore (1944) has recently given an account of a flourishing new agar industry which has arisen in New Zealand as a result of the war. Two species of the genus *Pterocladia* are principally employed, as they are found in commercial quantities in the North Island and around Kaikoura. Investigations have shown that renewal of these algae after harvesting is satisfactory, so they can be collected annually, e.g. *P. capillacea* regains its full length eight months after being cut. Reproduction of the species appears to occur throughout the year, though the amount of fertility differs greatly in the various habitats. The weed is collected by Maoris and sold by them at 9d. to 1s. a lb. to the manufacturing firm (Plate 7*b*). The larger weed, *P. lucida*, dominates in the material and the agar produced from it is of a good quality, both in colour and gel strength. and is therefore highly suitable for culture media and meat canning. During the first year of operation 60 tons of wet weed were collected and yielded 15 tons of agar, which was more than sufficient to cover the annual requirements of the country. It has also been established that *Gelidium caulacanthum* yields a good agar, but it is not yet being used commercially.*

Other Countries. An agar industry, as distinct from the production of dried weed, commenced just prior to the last war in the Netherlands Indies. Tseng (1944*a*) reports that two factories were in existence in 1938 but their output was not known. Whether this industry will be restarted it is at present impossible to say.

European countries, apart from England, do not appear to have interested themselves in agar manufacture or if they have

* It has since been reported (*Auckland Herald*, Oct. 9, 1946) that in 1945 105 tons of wet weed were collected and in 1946 110 tons of wet weed.

the relevant details are not available.* The French have in the past made several attempts to produce a home product, but up to 1940 no satisfactory result had been obtained. In 1876 a substance called "alguensine" was produced and this was moderately satisfactory, except that under certain conditions it tended to yield a liquid rather than a jelly.

In 1941 investigations were carried out in India with a view to exploring the use of agar from a species of *Gracilaria* (Bose, 1943). This work resulted in the production of two grades of agar, the seaweed yielding 43 per cent. of its dry weight.

This concludes the account of agar manufacture in the various countries, but before proceeding to describe its uses it is desirable to give some details of the chemical composition of agar and the raw weed material.

Chemistry of Agar and Agarophytes. The gelatinising material in all the various red seaweeds that have been used in the manufacture of agar or agariferous materials is often referred to as gelose. Sauvageau (1918) has pointed out that the gelose-producing algae can be divided into three groups on the basis of the setting power of the gel.

(*a*) *Gelidium* type: decoction sets firm if dilute.
(*b*) *Gracilaria*, *Eucheuma* and *Hypnea* type: decoction sets firm if in medium concentration or if electrolytes added.
(*c*) *Chondrus* type: decoction only sets firm if concentrated.

The third type will not be considered in this connection, as it has other more important uses, and the account is deferred to a later page (cf. p. 155). The differences between the three types have been further emphasised by Holmes (1907), and in the following table from this worker it will be observed that the melting point of the jelly from the different sources varies. This fact is of considerable importance in bacteriological work.

	Parts required to gelatinise 1,000 *parts of water*	*M.P. of jelly in °F.*
Gelidium corneum	8	90
Gelose (*Gelidium* extract)	4	90
Chondrus	30	80
Carragheenin (*Chondrus* extract)	30	70
Isinglass (country not stated)	32	70
Eucheuma spinosum	60	90

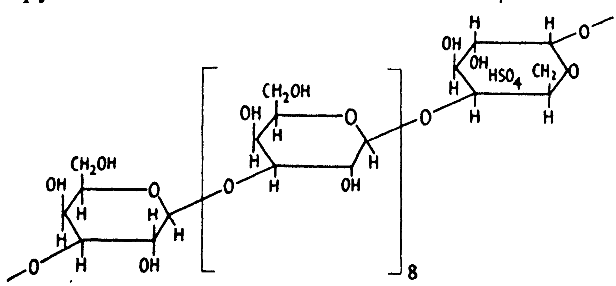
Analyses of commercial Japanese agar-agar show that it

* The presence of agar has been reported in Italy from the red alga *Spyridia* but no mention is made as to its utilisation (Cioglia, 1940).

contains on an average 16–20 per cent of water, 2·3–5·9 per cent protein, 0·3–0·55 per cent fat, 67·85–76·15 per cent carbohydrate, 0·8–2·1 per cent of fibre, and 3·4–3·6 per cent of ash. Matsui (1916) gives some interesting figures for the composition of three different algae used in Japan for the manufacture of agar, and it will be observed that their composition is somewhat different from that of the commercial agar.

	Main source	*Subsidiary sources*	
% of dry material	*Gelidium amansii* (Tengusa)	*Camphylaeophora hypneoides* (Yego-nori)	*Gracilaria sp.* (Ogo-nori)
Ash ..	4·23–6·16	3·04	3·54–6·71
Nitrogen ..	2·01–2·97	2·19	0·69–1·44
Fibre ..	17·89–14·71	12·25	4·32
Galactans ..	23·7	24·88	22·14–22·70
Pentosans ..	3·23–4·87	2·13	1·94–2·18

The "gelling" material of Japanese agar has been subject to considerable study, especially within the last ten years. At one time it was thought to be a γ-galactose united with sulphuric acid in the form of an ester. There would seem little doubt that it is composed of galactose residues united together in chains, according to Jones and Peat (1942), ten such residues forming a unit chain.* These workers maintain that there are nine *d*-galacto pyranose residues combined mutually by a 1 : 3 glycosidic linkage, whilst the chain is terminated by a tenth residue of *l*-galactopyranose. Their formula is as follows:†



* According to Barry, Dillon and McGettrich (1942) open-chain galactose residues cannot exist in the agar molecule because it is very resistant to oxidation.

† Earlier workers (Butler, 1934; Haas and Hill, 1921; Hoffmann and Gortner, 1925; Takahashi and Shirigama, 1934) concluded that agar was the calcium salt of an acid containing an ethereal sulphate and that the formula was of the type $R{-}R_1\ (OSO_2O)_2Ca$.

According to this formula the *l*-galactose residue is attached to the rest of the chain through carbon atom 4, and is further esterified at carbon atom 6 with sulphuric acid. In nature it is now generally accepted that agar occurs as the calcium or magnesium salt of this sulphuric acid ester.

According to Jones and Peat (1942), the HSO_4 fulfils a similar function in the biological synthesis (e.g. in the alga) of agar as that of the phosphate radicle in the synthesis of starch from glucose in higher plants. They consider that the change from the *d*- to the *l*- condition takes place by an intramolecular, oxidation-reduction change. The formula above requires a sulphur content of 1·8 per cent, but analyses show that the content actually varies from 0·5 to 1·5 per cent. This is barely sufficient, and so other workers (Percival and his school) consider that the SO_4 group is removed during the life of the plant when a 3,6 anhydro-*l*-galactose is formed, together with an ethereal sulphate. Barry and Dillon (1944) perhaps provide an explanation of this discrepancy by assuming that there are as many as 53 galactose units to each SO_4H group with at least 140 such units to each non-reducing end group. The same is also true of agar manufactured from *Gracilaria confervoides* and *Gelidium crinale* (Percival, 1944). Buchanan *et al.* (1943) have shown that the galactose residues in Carragheen polysaccharides have the same 1 : 3 glycosidic linkage as in agar, with an ethereal sulphate on the C_6 atom. Whilst this recent work has materially aided our understanding of the composition of the agar molecule it is evident that further work is still required.*

In the past the source of the material has not been clearly stated, and whilst in the majority of cases it has undoubtedly been Japanese agar, nevertheless it has been shown (p. 98) that this is rarely obtained from a single red seaweed.

When agar is hydrolysed by acid, a free "agar acid" is produced which will not gel until neutralised by the addition of a base. The salts of this acid have been prepared and they gel as readily as does natural agar (Fairbrother and Mastin, 1923; Hoffmann and Gortner, 1925). Tseng (1945*a*) suggests that this acid be called agarinic acid, so that natural agar would then be calcium agarinate. The principal sugar produced as a result of hydrolysis is galactose, though pentoses have also been reported (Takahashi and Shirigama, 1932; Miyake and Hayashi, 1939).

* Recently Dewar and Percival (1945) have obtained a 2 : 6 dimethyl β-*d*-galactopyranose from *Gigartina stellata*. This is the first dimethyl galactose to be obtained in crystalline form from natural sources.

It has already been made clear that the introduction of ions into various agar materials has an effect upon the tensile strength of the gel. The following lyotropic series of cations has been established (Pavlov and Engel'shtein, 1936), the effect being in descending order: caesium, rubidium, ammonium, potassium, sodium, lithium, calcium, barium, strontium. The corresponding anion series is: nitrate, bromide, sulphate, chloride, iodide and acetate (see addendum, p. 249).

There are several interesting physical properties of agars which vary, depending on the source of the agar. One of these is hysteresis or the lagging in response as a result of changed conditions. Thus in *Gelidium* agar there is a range of 40°C. over which the solution may exist either as a sol or a gel depending on whether it is being cooled or heated. In the case of *Hypnea* agar hysteresis is also affected by the presence of electrolytes.

All gels have a tendency to shrink with the elimination of tiny droplets of water. The droplets contain a higher concentration of solutes than were present in the original sol. This phenomenon is known as syneresis and it varies inversely with concentration of agar in the gel. The degree of imbibition of water by dehydrated agar is primarily determined by the moisture content and nature and concentration of the solutes. The acidity of the gel is also of importance and both cations and anions exert an effect in order of a lytropic series. For *Gelidium* agar this series appears to be the reverse of that for *Hypnea* agar.

In the light of the information that has been presented above, it is justifiable to conclude that the agar produced from red seaweeds, other than *Gelidium*, is probably in many cases composed not only of galactose but also of closely related substances with similar physical characteristics. At present, however, very little information is available about the chemical composition of agar made from war-time species in the different countries, but it is clearly not a uniform commercial product. Although commercial Japanese agar contains 67–76 per cent galactose, the raw algae do not contain so much because it becomes concentrated during manufacture. Thus *Gelidium cartilagineum* contains 40–45 per cent galactose (gelose), *G. amansii* 25–35 per cent, *G. pulchrum* (=*G. australe*), 32–37 per cent and *Gracilaria lichenoides*, 70 per cent.

Not only, therefore, are there probable differences in chemical composition as between the parent materials in the different

algal species, but there are also the differences in the composition and physical properties of the manufactured product. It is most desirable that a refined and purified product should be secured and which could be standardised, especially in respect of the temperature of transition from liquid to gel, the gel strength, elasticity, viscosity, transparency, ash content and content of impurities. Such a product, it has been suggested (Humm and Wolff, 1945), might well be marketed as "bacteriological agar".

It is perhaps somewhat surprising to learn that the agar with the strongest gel strength comes from *Gracilaria confervoides* of North Carolina. If this is recorded as 100 the relative strengths of other comparable agar gels is as follows (Lee and Stoloff, 1946): Californian *Gelidium* agar 69, South African *Gracilaria* 52, Japanese agar 42, Californian *Gracilaria* agar 30, Australian *Gracilaria* agar 26. It is probable that these figures would vary from sample to sample so that they merely indicate a general trend.

Apart from investigations into agarinic acid and the sugars of hydrolysis, it has also been suggested (Robbins, 1939) that commercial agar contains a growth substance akin to the auximones of plants. Although there is some evidence to support this view, the present author feels that its unqualified acceptance would not be justified in the absence of additional information.

Uses of Agar. The uses of agar are manifold, but probably its most important use is in bacteriological and fungal culture work, because after nutrient materials have been added even a dilute solution sets to a firm jelly upon which the bacteria or fungi can grow. Although this is its most important use, the actual quantities of agar employed form only a small portion of the total produced. The melting point of the agar is of the greatest importance, and for this reason the material produced from some of the red seaweeds is unsuited for this type of work. Bacteriological agar remains liquid when cooled to 42°C. and hence organisms can be thoroughly distributed within it at a temperature which will not hurt them. It also remains a firm gel at 37°C., which is the temperature commonly employed for incubating bacterial and fungal cultures.

Another reason why it is so valuable for bacterial cultures is that it resists liquefaction, e.g. many bacteria convert solid media such as gelatine into a liquid solution. There are, however, some agar-digesting bacteria, the best-known probably being *Vibrio agar-liquefaciens*. Recently twenty such bacteria

have been isolated from marine habitats (Humm, 1945), and in similar places three agar-digesting actinomycetes have been discovered (Humm and Shepard, 1945).

The first use of agar for culture purposes dates back to 1881 when Frau Fanni Hesse suggested it to her husband, though it was probably not known in its present-day form, but was supplied as the dried seaweed (Hitchins and Leikind, 1939). The first published note of its use, however, was by Robert Koch in 1882.

Different nutrient materials are added to the agar, depending upon the type of organism which one intends to grow. Thus, there is malt agar, potato agar, heart extract agar and so on. Some of the bacterial organisms (germs) which are grown on agar are highly coloured, and in certain cases the colour of the colony can be altered by changing the type of agar nutrient. Only the best and purest agar can be used in much of this work, and so there is a considerable demand for it.

Apart from its value for the culture of micro-organisms agar has a variety of other uses. A rather interesting use in a number of countries is concerned with the transport of preserved cooked fish, which is protected from breaking by being embedded in the firm jelly. It also prevents the constituents of certain fish, e.g. herrings, from blackening (detinning) the contents of the can and so rendering it unsaleable. The greater part of the agar required by Australia is used for this purpose, whilst New Zealand uses about 13 tons per annum for canning sheep's tongues. A somewhat similar use is seen in hot countries, where it can be employed as a temporary preservative for easily spoiled foodstuffs by cooking them with some agar.

Another industrial use of agar is in connection with the sizing of fabrics, but as it is much in demand only the finest grades of agar are used for the valuable silks, though poorer grades can be used for nansooks, muslin, voiles and tulles. The best agar has to be used for silks because it is most important that the sheen should not be destroyed. Japanese agar is stated to be definitely superior as a sizing material to products obtained from Irish moss (*Chondrus*) or *Gigartina*. Poorer qualities of agar are used as a coating in paper manufacture, in making waterproof paper and cloth, as a glue and as a cleaning medium for liquids. Some additional information about the use of agar in cosmetics and medicine is given elsewhere (cf. p. 215).

An unexpected use is as a lubricant in the hot drawing of tungsten wire for electrical lamps. For this purpose a suspension

of powdered graphite in agar gel is used. A very promising use of agar is seen in the photographic industry for making plates and films. Early attempts were not satisfactory because of difficulties encountered in adding certain chemicals, which make the emulsion sensitive. These difficulties have now been overcome, and the agar is regarded as superior to gelatine because the film need be only one-eighth the thickness of a gelatine film; it is also soluble in water, does not melt in tropical heat and is cheaper. Agar is also employed to a considerable extent in the finishing processes of leather manufacture, in order to impart a gloss and stiffness. It is sometimes a constituent of high-grade adhesives, and as such is used in the manufacture of plywood. In cooking it is invaluable for thickening soups and sauces, whilst it is also used for making jellies because it is more economical than gelatine and sets readily. It is widely employed in both Europe and America as a thickening agent in the manufacture of ice-creams, malted milks, jelly candies and pastries. In the preparation of sherbets, ice-creams and cheeses its function is mainly that of a stabiliser and to give smoothness. It has, however, a low whipping capacity, so that gums have to be added.* It has also been used in the manufacture of cream cheeses (Dahlberg, 1927; Marquardt, 1903) as a means of improving the texture of the cream. It has also been used in making icings, custards and mayonnaise (Hart, 1937). A product known as "imperishable milk" has also been marketed in the U.S.A. in which the cream is separated from the solids and then emulsified with agar. This process removed most of the foods for the growth of bacteria and so kept the milk fresh.

The principal potential food material in agar is the carbohydrate or galactose, but Swartz (1911) has shown that very little of this in ordinary agar is digestible, although, if the galactose is first hydrolysed, up to 50 per cent may subsequently become digestible. As a result agar is not used to modify the nutritive value of the foods with which it is incorporated, but instead to form a jelly which will preserve them against the action of the air, or else to stiffen liquid products which are more suitable for consumption in solid form. It is also extremely useful as roughage. Agar is sometimes used in place of pectin for making jellies, jams, marmalade and preserves.

The Japanese, strangely enough, use less agar for food as compared with their other algal products, but it is used extensively as such in China and Indo-China. In both these latter

* It is now largely being replaced for this purpose by sodium alginate (p. 202).

countries it is sold to poor coolies by travelling mobile canteens. The proprietors of these vehicles offer badly cooked rice or bowls of rice flour, small fishes grilled or fried, some vegetable floating in soya bean sauce, and at the finish a faintly scented agar jelly. It is very doubtful whether the coolie obtains any energy from the jelly, but it serves as roughage, and agar also has a very valuable laxative action. It is sometimes served as a substitute for the expensive "bird's nest"; whilst in Japan it is often cooked with rice to form "agar rice".

An important use in western countries is in connection with the brewing of beer and the manufacture of wines and coffee, where the agar is used as a clarifying agent (cf. also p. 215). It also finds a use as a pill excipient, as a base in shoe-stains, shaving soaps, cosmetics and hand lotions, and is sometimes employed as a stabiliser in chocolate drinks. There is perhaps one use which may be very important in war-time; this is in connection with wound dressings because agar contains a principle that stops blood clotting and thus enables wounds to be properly cleansed. Another somewhat unexpected use is as an activator in nicotine sprays that are used by gardeners in their war against garden pests. It is not completely satisfactory in this case, because there are difficulties in dispersing it through the spray liquid. It is also employed in the making of moulds required by those who model in plaster of Paris. A very recent use in this category is as a mould for the casting of artificial legs. Other uses are as a raw material in making linoleum, artificial leathers and silks; as an insulating material against sound and heat; as an ingredient in water-base paints and in the manufacture of storage batteries for submarines.

In order to show how the consumption of agar is distributed, Tseng has estimated (1945*b*) the annual amounts used in the different categories for the U.S.A., and these are given in the following table.

Estimated Annual Agar Utilisation in the U.S.A.

As laxatives	100,000 lb.
Microbiological and culture media	100,000 ,,
Bakery industry	100,000 ,,
Confectionery industry	100,000 ,,
Dental impression moulds	75,000 ,,
Meat packing	50,000 ,,
Emulsifiers	50,000 ,,
Cosmetics	25,000 ,,
Miscellaneous	50,000 ,,
	650,000 lb.

At one time agar was used in France in the production of imitation black-currant jelly, but this was exposed by a professor in the School of Medicine at Nantes. The method of discovery was rather interesting because it was entirely due to the presence of another alga. M. Menier was examining the preserve under the microscope when he noted in it a small diatom, which he knew was to be found in Japanese and not in European waters. Further study then showed that the preserve was a complete mixture of artificial substances including agar.

It can be seen from the above list of uses that agar-agar is one of the more important seaweed products in the world with wide applications. It is in fact one of the few algal industries that can be regarded as flourishing, and which is likely to remain so and perhaps even gain in importance.

CHAPTER VI

SEAWEED AS FOOD—I

Seaweed as Animal Food. Historical records show that the use of seaweeds in agriculture is a very old and widespread practice wherever there are rich supplies, and in this chapter it is intended to consider their application in some detail. This involves their use not only as food for animals, but also as food for the soil, i.e. manure.

The former of these two aspects may be considered first, and at the outset we may note that in a number of countries the animals regularly feed in certain regions upon fresh seaweed or upon a prepared seaweed food. Thus in Iceland fresh seaweeds are commonly employed as a food for sheep, cattle and horses; the animals are encouraged to stay browsing on the shore during the whole of the winter, and in some places during the summer as well. In many cases the seaweed forms almost their only food, though it is sometimes given them along with hay. In spite of their peculiar diet the animals do very well, and are said to provide excellent meat for human consumption. Horses prefer the "sugar wrack", *Laminaria saccharina*, of which they eat the basal or youngest parts, because these plants grow from an intercalary region just above the stalk. Elsewhere in Europe this particular seaweed is said to be distasteful to cattle. For stall feeding of cattle the Icelanders use dulse (*Rhodymenia palmata*) and "marinjarin" (*Alaria esculenta*), without the smell or taste of the milk being affected.

The Icelanders lay in a store of seaweed for a winter supply by washing the plants and then packing them in trenches where they are compressed with heavy oak planks and stones. When required the compressed mass is broken up and fed to the animals. Sometimes *Alaria* is air-dried, after it has been washed, and then stored in layers in barns, each layer alternating with a layer of hay. The Finns also use both *Laminaria* and *Alaria* as fodder for their cattle.

Norway. In certain coastal areas of Norway the sheep are regularly fed on seaweed, and after several generations it has been found that they digest it far better than sheep from the

interior. This is in accordance with experimental evidence on the utilisation of seaweed foods (cf. p. 132). *Ascophyllum* must also have been used on the farms because the common name in Norway is "grisetang" or pig-weed. According to Foslie (1884) *Fucus serratus* and *Chorda filum*, together with the stipes and fronds of *Laminaria digitata*, were given during the winter as an additional food to cattle. *Alaria* was also used in stall-feeding for cattle and thus obtained its local name of "kutara" or cowweed.

Scotland. In Scotland sheep and cattle wander down on to the seashore and eat the various algae. According to Hendrick (1916*a*) the sheep tend to feed more exclusively on dulse, which they often pick out carefully; the cattle, on the other hand, favour *Alaria*, *Laminaria cloustoni* (tangle) or the fronds of *L. digitata*, which they pick out from amongst the driftweed. No doubt quantities of *Fucus vesiculosus* and *Ascophyllum* are also eaten by sheep and cattle.

In the most northerly island of the Orkneys, North Ronaldsay, there is a local race of small black sheep which feed entirely on seaweed. The whole island, which is about 3 miles long by 1–1½ broad, is surrounded by a wall which keeps the animals out on the shore. Here some 2,000–2,500 sheep used to browse but the number is rather fewer now. They are allowed to enter a pasture only when in lamb or just before slaughter. Opinion differs as to whether the meat tastes fishy or not as a result of this diet. The wool is said to be of a superfine quality, but this is hard to believe when the rank matted condition of their coats is observed. Throughout the Orkney Islands, Spence (1918) notes that *Pelvetia canaliculata* (channel wrack) is known by the name of "cow-tang" because it is preferred by the cows, whereas fruiting plants of bladder wrack are known as "paddy-tang" because they are favoured by the pigs, which mainly devour the swollen, succulent, reproductive side branchlets. However, on the west coast of Scotland, in the region around Loch Feochan, channel wrack and not bladder wrack is fed to pigs when they are being fattened for market. This means of fattening pigs is still used, and the weed is either given raw or else boiled up and mixed with oatmeal, when it is also fed to calves.

In connection with the feeding of calves another alga also had an ancient use in the western Highlands. In West's treatise on the Fresh-water Algae (1912), it is recorded that the blue-green alga, *Gloeocapsa magma*, which grows on the peaty soils of the Highlands, was known as "mountain dulse", and after being

rubbed into a homogeneous mass was used for purging calves. In Ireland, Irish moss (carragheen) was employed in order to fatten cattle and to cure them of debility.

France. Various authors, e.g. Sauvageau (1920) and Deschiens (1926), have told how in Normandy and Brittany dulse (*Rhodymenia*) is readily eaten by cattle, and indeed at Roscoff it is known as "goémon à vache" (cow-seaweed) or "goémon à bestiaux" (animal seaweed). In France the animals are seldom stall-fed with seaweed, though an exception occurs in the Isle de Seine, where freshly gathered weed, after washing in fresh water, is mixed with some bran in warm water. In Normandy a mixed meal of sugar wrack (*L. saccharina*) and bran is used for feeding pigs.

America. Turning to countries outside Europe, we find a similar tale. Fresh seaweed is used for animal feeds on the American coast, where it is said to have increased the health and fertility of both cattle and poultry. On the Pacific coast *Macrocystis* is regarded as especially valuable because it contains vitamins A–E, but "maiden's hair", or *Desmarestia*, which is a genus of large brown seaweeds that occur in some abundance, is the very reverse of valuable, because in this case the plants are believed to be poisonous to cattle. This property may be due to their high acidity, which is said by Wirth and Rigg (1937) to be caused by a high content of free sulphuric acid.

New Zealand. In New Zealand, sheep are reported to eat the rockweed, principally species of *Blossevillea* (*Cystophora*) and *Sargassum*, together with the sea grape or *Hormosira*.

Seaweed meal, as distinct from the fresh algae, has also been used with great success as an additional feed for cattle on poor pasture land. Its importance in this respect can best be illustrated by an extract from the *New Zealand Weekly News* of July 16, 1941, where the writer says:

"Some years ago, when I came to this country, I bought a farmlet of eight acres. It was the poorest gum (from kauri gum) land and in my ignorance I did not realise then what that meant. I did not learn that only one cow had been kept there, and I put three on. They died. A veterinary surgeon said that both food and water lacked minerals. I obtained three bags of fish manure and three bags of superphosphates, all I could afford, and then thought of seaweed. It was difficult to get, the *Hormosira* or grape variety only being available and that is the poorest of all, but later I managed to get a little kelp. I soaked the salt out,

mixed the chopped weed with a little bran, sometimes a little molasses, and it was wonderful to see the cows go for this food.

"I now have an old cow decidedly growing younger after four years of seaweed rations; another cow, a picture of health, fed on this ration from birth, one little black Jersey, bought when in a starved condition and in calf (she comes in now with four and a half gallons), and two heifers used to the seaweed ration from birth. Nothing has been done to the land all this time, no manure, no lime and no cultivation, and yet the animals are all good and enjoy perfect health. When spring growth of grass comes one would expect the cows to leave the seaweed ration for the green growth, but not so. They are just as eager for the seaweed then as in winter."

Cattle Feed Factories. There is no doubt, even without this testimony, that seaweeds can be useful for cattle feed, and because of this factories have been built in various parts of the world in order to manufacture cattle food, principally from brown algae. In the fermentation process of the Pacific coast industry, some of the weed left after fermenting was dried and made into a form suitable for cattle, whilst a factory was established in Los Angeles devoted to the production of cattle, poultry and pig feeds from dried seaweeds. Farmers in parts of the U.S.A. have been accustomed to the use of seaweed meal for some time. The material is regarded as a protein concentrate, and is often given to stock in the proportion of 10 per cent of the total ration by weight. On one occasion the Overbrook dairy herd in the U.S., with dried seaweed in their ration, won the world's herd record for milk production.

Other factories have been built in Denmark, Norway (at Harstead) and in the Orkneys (Stronsay) for the preparation of cattle or poultry meal. Hoffmann (1939) records that the Norwegian factory was not working in 1939, but a herring meal factory in Norway produced as a side product 500 tons of seaweed meal in 1937, though the same concern made very little in 1938. The amount this firm produces probably depends upon the success or otherwise of the herring fishery. Researches on the uses of seaweeds for animal feeds were being made in Germany immediately prior to the last war, and, according to an anonymous author (1944), feed was later produced in a Norwegian factory during the German occupation.

The products of the Orcadian and Norwegian factories are largely composed of ground-up rockweeds (species of *Fucus* and

Ascophyllum), but they are said to be only coarsely ground in the case of the Norwegian product. In the Orcadian island of Stronsay, some dried *Laminaria* is also used: the meal is prepared here by drying and grinding, and is mainly used for blending in small quantities (1–2 per cent) with other meals. The Danish factory referred to above make an effort to render their meal more digestible, because experiments had shown that seaweed meal was not readily digested. In order to achieve this purpose the crude weed is cooked with superheated steam, drained and pressed into cakes. These cakes are then dried in a vacuum and ground up.

A meal prepared from species of *Laminaria* is sold under the trade name of "Algit", and pigs are said to thrive on this material, although its digestibility is lower for them than for sheep. Another meal prepared from bladder wrack (*Fucus vesiculosus*), black wrack (*Fucus serratus*) and knobbed wrack (*Ascophyllum*) is known commercially as "Neptun", but the digestibility of this meal is lower than that of Algit. Both meals have some value in that they exert a strong laxative effect.

Food Value. Some attempt must now be made to answer the crucial question: what exactly is the real value of these cattle feeds as a food? It is evident that there was considerable exaggeration of the nutritional value of such meals in the first world war, though claims have since been made (cf. p. 43) that seaweed meal increases the fertility and birth rate of animals. However, even as late as 1937, the *Deutsche Fischwirtschaft* of May 23 stated that the Norwegians had found that 1–2 kilograms of dried seaweed were equal to 1–2 kilograms of concentrated food, and that this meal brought about a rise in the milk output of cattle and in the egg-laying of poultry. It was further calculated that if each animal in the country were fed on 500 grams of seaweed per day, they would be able to use 445,000 tons of dry seaweed, which is equivalent to about 20 per cent of the annual Norwegian hay harvest! Subsequent inquiry has not provided any substantiation of these claims.

A first test of the relative nutritional value of these meals can be made by comparing analyses of the raw weeds and their commercial products with other regular fodder. This, however, does not lead to direct conclusions, because there is still the problem of relative digestibility. However, for purposes of making a first comparison a number of analyses have been collected together in the following table:

Dry Material	% *Water*	% *Raw protein*	% *Fat*	% *Ash*	% *Fibre*	% *(Carbohyd.) N-free ext.*
Fucus vesiculosus + F. serratus	12·4	4·95	1·95	13·1	5·5	62·0
Fucus serratus + F. balticus	12·3	4·4	0·8	16·0	5·65	68·85
Ascophyllum nodosum	11·1	5·96–6·86	3·3–3·76	17·8–20·09	5·8–6·51	56·0–62·78
Laminaria cloustoni[1]	12·4	5·86	0·77	13·67	3·6	63·68
Laminaria saccharina[1]	14·6	6·37	0·7	16·64	3·28	59·4
Laminaria digitata[1] (rich in laminarin)	18·6	5·8	0·6	11·3	26·7	36·6
Laminaria digitata[1] (poor in laminarin)	18·6	9·0	0·6	11·3	26·6	47·0
Kelp used in hog rations (Purdue Univ., Indiana)	7·3	11·4	1·0	38·5	8·4	33·6
Seaweed meal A	10·0	6·2	3·8	15·1	3·5	61·4
Seaweed meal B	9·1	5·6	0·4	38·5	5·8	40·6
Seaweed meal C	14·3	7·75	0·5	10·65	10·6	39·5
Seaweed meal D (Harstad)	6·5	7·0	2·8	19·1	6·2	58·5
Seaweed meal E (Denmark)	5·0	13·1	1·07	5·93	9·0	66·75
Seaweed meal F (Norwegian) (Beharrel, 1942)	13·58	6·9	4·40	16·10	5·07	35·95
Seaweed meal G (Scottish) (Beharrel, 1942)	15·50	10·9	1·5	27·5	9·30	35·3
Good hay	14·3	9·7	2·5	—	26·3	41·4
Oats	13·3	10·3	4·8	—	10·3	58·2
Potato tops	—	7·27	0·37	5·12	2·75	84·49

[1] According to Hoagland (1915) much of the nitrogen present in species of *Laminaria*, *Macrocystis*, etc., is not in the form of proteins.

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This table shows that the best all-round seaweed meal comes from Denmark, and that it is better than hay so far as the protein and carbohydrate contents are concerned, whilst Meal F from Norway is also as good as oats in the fat content. The figures also show that *Ascophyllum* and potato tops have comparable nitrogen (protein) contents, though in each case it is less than that of hay. Considerable differences are to be found in the carbohydrate content, whilst *Fucus* and *Ascophyllum* contain at least 20 per cent less carbohydrate than potatoes.

The analyses of raw plants and manufactured products vary from locality to locality, and are also dependent upon the season of the year and the relative proportions of the different parts of the plants in the samples. It is known, for example, that the carbohydrate content of the algae is highest in the autumn, and therefore meal prepared in the autumn should have the maximum nutritive value. In addition the composition of the commercial product depends upon the method of preparation (see also p. 128).

Although suitable food materials are patently present in algae, the extent to which they are digestible still remains a debatable problem. Beckmann (1915, 1916) used a bread made with finely ground seaweed, rye and potato flour, and he fed it to a number of animals, including dogs and hens. The same worker was able to demonstrate that pigs, cows, ducks and sheep can eat seaweeds for many months as an additional food, and that they thrive as well as control animals fed on normal foods. Brown rockweeds were the principal seaweeds used in these experiments, though the red alga *Furcellaria fastigiata* and the phanerogam *Zostera marina* were also tested.

In his preliminary experiments Beckmann (1915) used algal feeds obtained from commercial firms as well as the one concocted by himself (Feed C). Analyses of these feeds gave the following composition:

	Raw protein	*Carbo-hydrate*	*Fibre*	*Ash*	*Fat*
Feed A (Alga unidentifiable)	5·69	10·55	5·38	—	—
Feed B (*F. vesiculosus and F. serratus*)	5·69	7·28	6·29	14·95	2·24
Feed C (*F. serratus and F. balticus*)	4·98	13·91	6·45	18·28	0·89

Beckmann found that pigs fed on the above three meals increased in weight more than the control animals, but that under 50 per cent of the *Fucus* was utilised.

The composition of Feed C was probably materially affected by the presence of *F. balticus*, which is a brackish-water form, but no comparable analyses of brackish-water or salt-marsh forms appear to have been carried out elsewhere. This omission might be worth investigation; for example, *Pelvetia canaliculata* ecad* *libera* and *Ascophyllum nodosum* ecad *mackaii* both occur locally in some abundance, are extremely easy to collect, and would probably be easy to cultivate.

It has also been found that if the potash, bromine and iodine are removed seaweed meal can be substituted for oats in horse feed, although the nutritional value is not quite so great. In the case of *Laminaria* meal, the iodine was removed because it was believed that a high content would lead to a strong stimulation of metabolism and secretion, with a consequent loss of weight. Beckmann and Bark (1916) state that "the iodine-poor seaweeds [i.e. rockweeds] can be recommended without hesitation as an added food and as a vehicle for molasses and similar foods which are difficult to handle. It is specially recommended that when quantities of algae are thrown up on the coasts of the Baltic and North Seas they should be used there for feeding." They further state that it is not desirable to have more than a quarter of the feed in the form of seaweed meal.

More recently Lunde and Close (1936) found that when iodine is present in seaweed meal, it does not appear to affect either the quantity or quality of the milk of cows, although it resulted in increasing the iodine content of the milk. This, however, might prove very desirable in areas where the population suffers from goitre.

An indirect effect of the iodine in seaweed upon cattle has been reported by Marrett (1936) for the island of Jersey. Here the small size and bones of Jersey cows are said to be due to a deficiency in calcium together with a high iodine content in the grass, brought about by the use of seaweed as a fertiliser. It is further suggested that the use of the seaweed fertiliser may play a part in warding off bovine tuberculosis, foot and mouth disease and contagious abortion, from all of which dread diseases the cattle of Jersey are free.

* A term used to indicate that the form is one determined very largely by the habitat, in this case salt marshes.

Experiments have been carried out on the digestion of the various components in seaweed meal, and these show that much of the nitrogenous material is undigested. In the case of the carbohydrates (sugars), healthy animals appear to digest about 20 per cent, whilst those in poor condition will absorb up to 50 per cent. This probably explains the excellent results recorded earlier in the *New Zealand Weekly News* (cf. p. 126). Rabbits and dogs have been fed by Lorisch (1908) on agar prepared from red seaweeds and the animals utilised 50 and 67 per cent respectively of the sugars. The main result of all the experiments by the various workers is to show that different values for utilisation are obtained for different species of seaweed and for different kinds of animals. The data at present available are suggestive, but more extensive work would be desirable.

During the 1914–18 war experiments were made with seaweed meal as a substitute feed for horses (cf. also p. 43). Several accounts of these experiments in their different stages have been given by Adrain (1918), Lapique (1918), Lapique and Broc-Rousseau (1921) and Sauvageau and Moreau (1919). The results are distinctly contradictory, but it does seem certain that when *Laminaria* and *Fucus* are used it is the sugars which are most fully utilised. Adrain (1918) claimed that *Laminaria* formed a concentrated food of which 750 grams were equivalent to 1,000 grams of oats in food value, but this claim is certainly not justified. On the basis of the claim it has even been suggested that as 8–9 tons of wet weed would yield 1 ton of meal, one million tons of wet weed would provide the equivalent of 150,000 tons of oats!

About the same time Isaachsen (1917) tried the effect of feeding cattle on a mixture of *Fucus* and *Ascophyllum*, and he concluded that 1 kilogram of meal was equal to about 0·7 kilogram of moderately good hay. He suggests that the algae should be given to the animals in spring, but Lunde (1937*a*) has since pointed out that this would not be advantageous because the content of laminarin, which is the most easily digested component, is very low then whilst in the autumn it is much higher. It is evident that here we have a problem that is by no means solved. If it is the seasonal products, e.g. laminarin and mannite, which form much of the digestible material, then it is evident that further research is necessary because in the past little or no cognisance of the seasons has been taken in preparing the meals. Unfortunately experiments such as those mentioned above, are usually only made in war-time, and it would seem

important that someone should study this problem of the use of seaweed meal more fully and extensively.

During the last war a factory in Co. Clare, in western Ireland, produced a dried seaweed meal for stock feed. Experiments were carried out with this meal using two pigs as the experimental animals. The experiments extended over three periods, each lasting sixteen days. In the first period the pigs were fed on a basic ration, in the second some untreated *Laminaria* meal was added, and in the third hydrolysed *Laminaria* meal was used, because it was thought that this might be more digestible. In the second period the pigs digested one-quarter of the crude seaweed protein, one-half of the fibre, and three-quarters of the carbohydrates. There was no great difference between the digestibility of hydrolysed and untreated meal. The experimenters (Sheehy *et al.*, 1942) concluded that the chief value of the meal was in improving the amount of the basic ration that could be digested. They considered that the food value of the meal for pigs was about 2½ times that of potatoes, and that it lay between that of hay and oats. In seaweeds the starch that is formed by green land plants is largely replaced by laminarin, and they found that this at any rate was completely digested. Their results therefore agree with those of Lunde (1937), and serve to emphasise the importance to be placed on the correct season for collecting the algae. There is one aspect of the use of seaweed meal that does not appear to have received any attention so far. These algae contain many elements which are only present in small quantities. Some of these elements are of importance in the life of animals because they prevent what are known as deficiency diseases. It still remains to be discovered how far the use of seaweed meal may control the incidence of these diseases.

Seaweed as Manure. When we turn to the use of algae as food, i.e. manure, for the land, we find that it is largely the thick brown algae, wracks, oarweeds or kelps that are used. Other species have been employed if they are washed up in sufficient quantity, e.g. the sea-lettuce *Ulva*, which is rich in nitrogen, another green seaweed called *Entermorpha intestinalis*, and a red alga, *Soleria chordalis*. Driftweed that collects on the shore is never or but rarely composed solely of the brown weeds and it usually contains a good admixture of red and green algae. Hoffmann (1939) relates how in Schleswig-Holstein and Pomerania there is much utilisation of the *Fucus* drift; so much so that it is

even used as litter and afterwards put on the field with the stable manure. However, the greatest use of seaweed for the land is probably to be found in the north-west of France, where the coastal region is known as the "ceinture doré". Here, 400 miles of coastline are involved to a depth of 500 metres from the sea, and throughout this strip the peasants apply annually 30–40 cubic metres of weed per hectare. An early worker on this aspect (Mangon, 1859) calculated that the addition of 30,000 kilos of weed is equivalent to adding 49 kilos of nitrogen to the same area.

The driftweed known as "goémon épave", "goémon de dérive" or "goémon d'échouage" is primarily employed, though the value of this material will depend to some extent upon the length of time it has been drifting in the water. Its condition, i.e. degree of fragmentation, will also depend upon whether it has been exposed to much wave action. If it has been subject to considerable pounding it is finally deposited in a form which one could describe as "tea-leaf". When it has not been badly mutilated it is said that four women, aided by a man and a panniered ass, are able to collect as much as 6–8 tons in the course of a six-hour day. The French peasants also cut and collect the rock-weeds which grow below mid-tide mark, chiefly bladder wrack, knobbed wrack and black wrack. This material is known as "goémon de rive" or cut seaweed. As in the kelp industry the cultivators also used, though to a lesser extent, "goémon de poussant" or "goémon de fond", which refers to the various oarweeds growing *in situ* that are collected from boats.

At Roscoff very considerable quantities of the button weed (*Himanthalia*) are collected in the autumn and used as manure on the artichoke fields. In certain parts, e.g. the Ile de Ré, goémon épave is put on the barley fields just before the seed is sown, and then later a layer of goémon de rive is put on the young seedlings. The effect is said to be perfect, the fields of barley are magnificent and the crop is much in demand by brewers. The steady use of the seaweed manure has completely obviated any necessity for a rotation of crops, which would otherwise have to be practised. This fact, though, is somewhat surprising in view of the deficiency of phosphates in the algae (cf. p. 142).

In France the collection of the different kinds of goémon for manure is very strictly controlled. Anyone is allowed to collect goémon épave, but special permission has to be obtained for the other two types, and it is only given to those persons whose land adjoins the beach or to maritime municipalities.

In 1681 a royal ordinance laid down the regulations for cutting wrack. The five most important articles were as follows:

1. The inhabitants of the parishes situated on the coast will assemble the first Sunday in the month of January of each year, at the end of parochial mass, to regulate the days on which they may commence and end the cutting of the plants known as *vraicq* or seaweed, growing in the sea with respect to their parishes.

2. The assembly will be convened by the syndics, churchwardens or treasurers of the parish; and the result will be published and affixed to the principal door of the church and to the stage coach on the pain of £10 penalty.

3. It is forbidden to the inhabitants to cut weed at night or, except for the time set aside by the community, to gather other than in the region of the coast in their parish, or to sell to outsiders or to collect from other parishes on pain of £50 penalty with confiscation of horse and harness.

4. It is forbidden to Seigneurs of Fiefs to appropriate any portion of the rocks where *vraicq* grows, to obstruct their servants from removing weed during the time cutting is allowed, to exact anything from them or to give permission to non-residents.

5. It is permitted meanwhile to all persons to take indiscriminately at all times and at all seasons, the seaweed thrown up by the sea and to transport it where they wish.

In 1731 so much opposition had been aroused against the cutting of seaweed, on the grounds of damage to fisheries, that Louis XV ordered an investigation to be made, and as a result the cutting was restricted to certain months, a practice which has been more or less followed ever since. Thus, in 1868, two cuttings of rockweed were permitted each year in the region around Cherbourg, the periods being fixed by the municipal authorities. At Roscoff the first period lasts six days, usually in February, and the first three are reserved for those who use panniers and wheelbarrows to remove the weed, whilst in the last three owners of horses and carts and boats can also participate. At Plounéour-Trez cutting is allowed from January 15 to June 15, but nearly all of it takes place in May or June.

At present the cutting and collecting of seaweed in France is controlled by a decree published in 1890 together with some of the earlier decrees. According to Gloess (1919) the three types of goémon are defined in the latest decree as follows:

(*a*) Cut marine plants (goémon de rive) are those which are

attached to the ground and which may be reached dry-shod at low water of spring tides.

The term "dry-shod" has a somewhat liberal interpretation, because the regulation goes on to say that it is understood that cutters may go into the sea "jusqua la ceinture" or up to the belt!

(*b*) Marine plants growing in the sea and which cannot be reached "dry-shod" (goémon de poussant).

(*c*) Marine plants thrown up on the beach (goémon épave).

The cutting or collecting in some places is restricted to the "goémonniers", who may only collect it at certain times of the year. These times vary for different localities, and as they bear no relation to the life of the plant but are determined by tradition, it has been suggested that the weeds may often be collected when they are reproducing and so the future supply might be jeopardised. Observation on the shore suggests that this is hardly likely to happen, because most of the plants are perennials, and there will always be a growth of young plants which would be left untouched by the knives. Furthermore, the very great number of spores produced by a single plant of *Laminaria* (cf. p. 246) would help to make good any loss.

When the seaweed has been collected it is either dug into the ground fresh or else quickly dried in the sun and built into a stack. A modification of this process is used in Denmark and Canada (Shutt, 1914), whereby the seaweed is mixed, either with or without pounding, with peat. After two or three months it is decomposed and can be used for grain crops, especially barley, also for potatoes, vegetables and vines. However, Wheeler and Hartwell (1893), who gave considerable attention to this problem, came to the conclusion that no advantage was to be gained by composting in this manner.

Ireland. In the British Isles seaweed manure is still used fairly extensively on the west and south-west coasts of Ireland, and in one or two localities the species concerned are even cultivated (Plate 7). Potato sets are placed over what is virtually a layer of fresh seaweed, whilst in the autumn the manure is put on the stubble after the oats have been cut and it is also used on pasture land. The peasants think so highly of it that it may be conveyed, usually by panniered ponies, seven or eight miles inland (Plate 6). The bladder wrack (*Fucus vesiculosus*) is the species most commonly cultivated in those places where the farmers cannot find enough. Cotton has given an account (1912)

of how, in sheltered sandy bays, the farmers bring down stones, in size about one foot cube, and lay them in rows about three feet apart across the sand, leaving special paths for the carts. When the stones sink into the sand they have to be raised, but they must not be tilted because growth takes place best on the old exposed surface. It is only when there are too many unusable "weed" algae present that the stone is turned over. The yield from these farms must have been important because in 1912 a site consisting of three-eighths of an acre sold for £70. The weed is cut after two years' growth, and is made into stacks six feet high (Plate 9). These are tied together with ropes and towed ashore when the tide is coming in. Cultivation of this nature is carried out in Achill Sound and Clew Bay.

Scotland. In south-west Scotland the driftweed is more highly esteemed as a manure, but in north Scotland the crofters prefer cut rockweed (Plate 9). In the Hebrides driftweed is mainly used as manure, and it is regarded as specially valuable for barley crops. The ground is covered to a depth of three to four inches, but it is not ploughed in. This, as Macdonald (1811) says, is a somewhat wasteful method. A considerable amount of drift may be cast up on the Ayrshire coast and Hendrick (1898) records that the farmers there used to apply (and still do to a small extent) 25–30 tons of seaweed per acre in the autumn. It has been suggested that this driftweed is brought by westerly gales from such far distant shores as Arran, Kintyre and even Ireland: this, however, is certainly a statement which requires confirmation. It is recorded that the price of land in Ayrshire in 1868 was enhanced by 30s. to 40s. an acre if its ownership was accompanied by the privilege of gathering seaweed.

Up to 1898 the farmers of Aberdeen and the neighbouring regions used to employ seaweed as a manure, but since then its use has decreased for several reasons. Chemical manures have become cheaper and are more easily available; there has been an increase in labourers' wages; the labourers themselves have become more exacting and feel that the collection of seaweed is a degrading occupation, and finally the soils of Aberdeenshire, as compared with those of Ayrshire, are initially richer in potash and therefore less in need of this substance from seaweeds.

Moffat records that, in 1915, 25,000 tons of crude potash were used alone in Scotland for manure, and that this tonnage was four times the quantity used in England. Under these circum-

stances one would have thought that there were good grounds for furthering the use of kelp ash or the raw weeds as manure because the supply is so readily available. In this connection a rather interesting fact may be noted here, which suggests the need of further study: analyses tend to show that east coast seaweeds are not so rich in potash as those of the west coast; this is a point that requires further confirmation and also some explanation.

At one time seaweed was used in the Shetland Isles for manure, and a relic of this usage is to be found in the local name "tarri-crook" for a dung fork: this literally means "seaweed fork."

England. Agricultural practice in southern England is rather different from that of Scotland, because in Cornwall the seaweed is first mixed with sand and allowed to rot before being used at the rate of about 10–12 tons per acre. In the winter of 1944, seaweed manure collected in Cornwall was advertised for use on the land, but in general transport difficulties are probably responsible for restricting its use mainly to regions near the centre of collection.

In both the Scilly and Channel Isles seaweed manure also forms an integral part of their agriculture and has done so for many centuries. In the various islands the different species possess different values to the farmers, e.g. in Jersey *Fucus serratus* is the species most highly regarded. In both groups of islands the usual practice is to put on about 45–50 tons per acre in the autumn where it is intended to grow early potatoes. In some islands the weed is allowed to rot first and then less is required, e.g. about 14 tons per acre. The Jersey farmers, however, according to Wheeler and Hartwell (1898), did not use seaweed for their potatoes because it was said to give the tubers a disagreeable taste. On the other hand there is also a report that potatoes grown on land manured with seaweed are less susceptible to scab disease and also to the virus disease known as leaf curl, but this would seem to require further confirmation. Le Cornu (1859) has described how the Jersey farmers were wont to use fresh *Fucus serratus* for their root crops whilst for the wheat they employed kelp ash.

In the eastern counties of Great Britain the use of seaweed as a manure was previously much valued in the Isle of Thanet. Here special passages were cut through the 50–60-feet cliffs in order that the weed could be removed from the beaches, and these passages still retain their old Scandinavian name of

"gates". The usual agricultural practice was to put on 10–15 tons of weed per acre in the autumn, and then to rake off the débris again in the spring. Farther north on Blakeney Point, in Norfolk, the bird watcher often used seaweed manure for his potato crop on the dunes and obtained excellent results.

The possibility of exploiting algae for manure has also been considered on the south coast of England, at Worthing. Here very considerable quantities of seaweed are cast up on the beach in some years, a very high proportion being Rhodophyceae. An anonymous writer (1937*c*) has said that as much as 30,000 tons may be cast up, but from experience on other parts of the coast, which have shown how easy it is to over-estimate quantities of castweed, this figure is almost certainly too high. It has been suggested that this supply could be used to start a fertiliser industry or asparagus farms. Another proposal was the establishment of seaweed baths for persons suffering from lack of iodine. All these plans would however be fruitless unless convincing evidence were obtained that regular large casts were likely to be thrown up annually.

One rather interesting use of seaweed, which may fitly be mentioned here, is in connection with the cultivation of tomatoes. Here it has been found that seaweed manure dug into the soil to a foot below the surface increases the fruiting period of the plants, and it has also been claimed that it renders them free from blight.

America. Algae are also used for manure outside of Europe. Thus on the Pacific coast of North America the big kelps are collected, and after being chopped up are used wet. There is therefore no transportation to a drying centre. This technique was used by a firm known as the Pacific Coast Mulch Company. Other firms attempted to dry weeds in the sun, but it was found that the viscous juice which they exude formed a kind of protective coat and rendered drying very difficult. The weed is now transported to a central factory and dried in large horizontal driers, about 50 feet long and 5 feet in diameter, which are capable of handling four tons of wet weed per hour. The dried kelp still contains about 15 per cent of water, but this is not a serious drawback. Farther north, in Alaska, *Alaria fistulosa* is regularly employed as a manure for potatoes and the results are extremely satisfactory (Plate 10). On the east coast of North America seaweed was also much used for manurial purposes. Kelp Day on the New England coast used to be a holiday of

note in the fall, when everyone went down to the beach to harvest the available weed. In Rhode Island, until quite recently, seaweed comprised an important percentage of the total manure used, e.g. in 1885 it formed one-quarter of the total agricultural manure, and in 1890 the farmers were paying five cents per bushel for seaweed.

New Zealand. In the southern hemisphere coast dwellers in New Zealand have made use of algae as manure. Various species are employed for this purpose: *Macrocystis pyrifera*, *Lessonia variegata* and *Ecklonia radiata* among the bottom weed species, whilst *Carpophyllum*, *Blossevillea* (*Cystophora*) and *Sargassum* are the principal rockweed forms. The cost of removal of drift-weed in New Zealand seems, however, to be somewhat expensive as it ranges from 12s. 6d. to 15s. per ton. It is often used around Auckland because there it has to be removed from the oyster beds. The principal objection to a more extensive use of seaweed as a manure in New Zealand, and indeed anywhere, is that it is heavy bulky material (it contains 90 per cent water), and, unless dried, it must therefore be utilised near its source. It is, therefore, only profitable to establish an industry in places where large quantities are likely to be continually available. Rapson *et al.* (1942) indicate that attempts are now being made in New Zealand to use dried and ground *Macrocystis* as a manure. Grimmett and Elliott (1940), for example, have prepared a dry manure from New Zealand *Macrocystis* which contained 17 per cent of potash and 2 per cent of nitrogenous material. The bull kelp, *Durvillea*, which is also abundant in these waters, would not be a satisfactory alga for manurial purposes since it only contains about 1·75 per cent potash and 0·7 per cent nitrogen (Aston, 1916). Field experiments carried out in New Zealand have shown that plots fertilised with this dried *Macrocystis* yield crops only slightly inferior to plots treated with an equivalent amount of artificial manure containing 30 per cent of potash salts. The minimum cost of collecting, drying and grinding the weed works out at £10 per ton of finished product, which compares very favourably with £20 per ton for 30 per cent potash. If these figures are substantiated there would seem to be considerable scope for the development of the industry in New Zealand (see also addendum, p. 253).

The sea contains a large amount of common salt, or sodium chloride, and it might therefore be expected that the seaweeds would also contain much sodium chloride, but in practice the

chloride is mainly present as the potassium salt. It is this capacity of the marine algae to accumulate salts of potash from the relatively dilute solution of potash, represented by the sea, that makes them so valuable not only for manurial but also for industrial purposes. It is for this reason that they are used as a manure in a number of countries for root crops such as mangold, sugar-beet, cabbages and potatoes. It does not appear to be suitable for vines, although it is used for that purpose in France. From the point of view of the farmer, seaweed manure is excellent because it contains no weeds or fungal pests. Although it has been said that the use of seaweed on pasture has no effect on the iodine content of the grass, this statement requires further confirmation, especially in view of Marrett's comments about Jersey cows (cf. p. 131).

Manurial Value. It is evident from the above that there is a fairly widespread, though locally restricted, use of algae as manure, and therefore it is desirable to consider to what extent these seaweeds compare with farmyard and other manures in value. At the outset it can be noted that they are all high in nitrogen and in potash, but they are low in phosphorus content. In order, therefore, to obtain the very best results from seaweed manure some phosphates should be added. Indeed the continual use of seaweed manure, without some balancing with artificial phosphates, is increasingly less satisfactory as all the phosphates become extracted from the soil. In order to illustrate these points one can compare the composition of one ton of average wet seaweed with one ton of average farm manure from western Scotland.

	Nitrogen	*Phosphoric acid*	*Potash*	*Common salt*	*Organic matter*
1 ton wet weed	7 lb.	2 lb.	22 lb.	35 lb.	400 lb.
1 ton farm manure	11 lb.	6 lb.	15 lb.	—	380 lb.

It will be seen that there is only a slight deficiency in nitrogen but that there is a relatively large one in phosphates. Unfortunately, although there is plenty of nitrogen present it is not readily available; in other words, it takes a long time to pass into the soil in a state in which it can be used by the plants (cf. p. 145). The available potash and organic matter in seaweed manure are rapidly used up by the plants, and for this reason the Hebridean crofters reckon that one cartload of farm manure is equivalent to 2½ loads of seaweed, because the effect of the farm manure lasts longer.

The next table compares the composition of the giant seaweeds of the Pacific coast with artificial manures, the values being based upon a standard potash content (Burd, 1915):

	Potash	*Sodium*	*Chloride*
Macrocystis	100	35·7	118·6
Nereocystis	100	33·8	125·2
Pelagophycus	100	24·8	117·6
Kainit	100	128·5	194·2
Carnallite	100	108·0	454·7
Sylvinite	100	154·3	337·8

From this table it is evident that the quantity of sodium chloride in these algae is not excessive in comparison with other manures. Moffat (1915) performed some analyses of *kelp ash* which was being used as a manure in Scotland. The sample contained 11·14 per cent K_2SO_4, 27·17 per cent KCl, 9·0 per

growing farther south, but that the reverse is true for the organic matter (cf. also p. 68).

	Org. matter	*Nitrogen % of[1] fresh wt.*	*% Phosphates (fresh wt.)*
Macrocystis. Leaves			
N. (Pacific Grove)	7·9	2·2–2·67	1·03
S. (San Diego)	9·5	1·25	0·73
Macrocystis. Stem			
N. (Pacific Grove)	5·5	0·75–1·11	0·57
S. (San Diego)	6·5	0·55–0·71	0·55

[1] Most of this is not present in the form of proteins (Hoagland, 1915).

The variations in the chemical composition of seaweeds in relation to change of latitude in the Pacific are extremely provocative. It is probable that the phenomenon is more widespread, but it will require additional analyses of samples on a far larger scale that heretofore before any interpretation becomes possible. When the explanation does become available it should throw considerable light upon the physiology of the different species.

The above table also shows that the composition of the different organs varies. This has already been noted in connection with the iodine and potash industry. The point may be further illustrated by figures for other species (Burd, 1915), and it will be noted that in the plants analysed the fronds are richer than the stipes in nitrogen and phosphates.

	% Nitrogen	*Phosphates (expressed as % of fresh weight)*
Nereocystis.		
Leaves	2·07	0·85
Stipe	1·23	0·52
Pelagophycus.		
Leaves	1·55	0·83
Stipe	1·00	0·56

Wheeler and Hartwell (1898) also found that the composition of East American species varied with the season, the nitrogen content being greatest in January and the potash in September. The time when the weed is applied to the land may therefore be of some importance, but at present our information can hardly be regarded as adequate. In the British Isles the evidence available suggests that the mineral and nitrogen content is at its maximum between January and May (Black, 1948 *et al.*). These happen to be the months when there are good casts, so that nature apparently works to give man the greatest benefit.

Although it is the giant kelps that are used for manurial purposes on the Pacific coast of North America, nevertheless one of the Californian littoral weeds, *Egregia menziesii*, and an oar-weed *Laminaria andersonii*, are known to be richer in nitrogen than the giant kelps whilst the former species is also richer in phosphates (1·79 per cent of dry weight). It is probable, therefore, that these species and other rockweeds would form a better manure. So far, however, no attempt appears to have been made to utilise them.

Figures have already been given comparing the composition of Pacific species and manures, so in the following table some figures are provided for European species of seaweed:

	% of fresh weight							
	L. digitata		*L. saccharina*		*F. serr.*	*F. ves.*	*Ascop.*	*Range*[1]
	stipe	leaf	stipe	leaf				
Water	82·9	75·0	83·2	78·5	76·3	68·1	69·6	68·0–83·2
Organic matter..	11·0	19·7	11·0	16·7	20·75	25·5	24·15	11·0–25·5
Nitrogen ..	0·22	0·3	0·3	0·2	0·3	0·3	0·3	0·2–0·8
Potash	1·83	1·2	1·9	0·95	1·0	0·95	0·80	0·8–1·9
Phosphates ..	—	—	—	—	—	—	—	0·2–0·17

[1] Includes information from various sources.

The comparison with comparable analyses of Pacific algae shows that the European species are not so rich in nitrogen and phosphates, but they are apparently richer than *Macrocystis* in organic content. This last feature may not be of great significance because it depends upon the proportion of organic material that can be converted in the soil into a suitable humus.

It is important to note that only fresh material should be used for such analyses because washing either by rain or artificial means removes some of the salts and results in false values. Thus Vincent (1924) found that dry material which had been washed five times with sea water—though the duration of the washings is not mentioned—lost 21·8 per cent of the initial weight. This lost fraction consists to a very large extent of carbohydrates, nitrogenous material and salts. On the other hand, the effect of washing serves as an indication of the rapidity with which the mineral salts become available.

The amount of potentially available nitrogen in the giant

kelps is 1–2 per cent, but it is only liberated slowly into the soil. The availability of the nitrogen appears to depend upon the type or condition of the weed, e.g. that of *Nereocystis* is readily available whilst that of *Pelagophycus* is not so. In the case of *Macrocystis* the availability of the nitrogen decreases on drying, so that it is desirable to use this alga when wet. It has been estimated that the organic matter of these three seaweeds is sooner or later converted to valuable humus (cf. p. 253), and that it increases the humic content of the soil to an extent comparable with a crop of alfalfa or stable manure and straw.

Many plants require minute quantities of certain elements if they are to grow properly. If sufficient of these trace elements is not present the plants suffer in the same way as animals (cf. p. 133) from what are known as deficiency diseases. The symptoms of these diseases are varied, but they frequently involve changes or "burning" of the leaves, and from these appearances a trained person can surmise what substance is lacking in the soil. Seaweed manure is particularly valuable because it contains a number of these trace elements, e.g. manganese, boron and barium. This aspect of seaweed manuring has, however, been more or less neglected.

Kelp ash, as prepared for the iodine industry, would be a valuable potassic manure although the nitrogen has been lost. Some figures from Hendrick (1916) for the ash of various species illustrate this point, and also enable some comparisons to be made. Thus, ash from the stipes of the *Laminaria* species is nearly twice as rich in potash as ash from the fronds. Hendrick's figures for the soda contents have also been included for comparison. These show that the rockweeds contain more soda than

	% *potash in soluble ash*		% *soda in soluble ash*	
	Min.	Max.	Min.	Max.
Laminaria cloustoni				
Stem[1]	7·0	12·67	0·62	1·3
Frond	2·26	9·4	0·36	1·55
L. digitata (*stenophylla*)				
Stem	7·64	15–16	3·17	6·03
Frond	2·74	7·31	4·49	7·12
Fucus vesiculosus	2·58	3·76	3·71	5·09
Fucus serratus	2·72	5·20	3·99	5·78
Ascophyllum	1·27	3·01	4·38	7·19

[1] Cf. footnote 1, p. 67.

potash, whilst the stipes of the oarweeds contain more potash than soda. It is interesting to note that in the frond of *L. digitata* the maximum quantity of the two minerals is about the same.

It has already been noted that analyses of kelp ash vary according to the type of weed, season of year (Fig. 28), and also the method of preparation. The effect of rain during the drying process may result in much of the valuable salts being leached

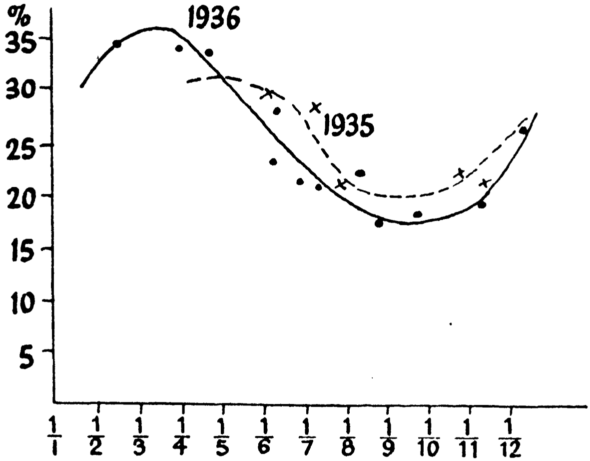


FIG. 28. Variations in the ash content of frond of *Laminaria digitata* (After Lunde)

out. Thus, Beckmann (1917) found that thorough washing reduced the ash content of knobbed wrack (*Ascophyllum*) by 14 per cent and of tangle (*Laminaria digitata*) by 13 per cent. All these possibilities have to be considered when investigating the use of kelp ash for manure.

The first comparative field experiments on the use of seaweed manure are said to have been made in 1880. They were, of course, only rough, but they demonstrated very clearly the superiority of yield in the fields treated with seaweed. Some more investigations at the beginning of the 20th century and later have provided additional and more accurate information. When seaweed and stable manure are applied to early potatoes there is no difference between the two crops, but if extra superphosphate is also added to the fields, then there is a big increase in the crop from the field with the seaweed manure, and little or no increase in the crop with stable manure. This suggests

that seaweed manure plus superphosphate is much better than stable manure. The experiments showed the superiority of seaweed in increasing the yield, but it was found that the cooking quality was not so good as that of potatoes grown with dung manure. This, however, could be overcome by giving the potatoes longer to mature when seaweed is used, and then there might be no difference in quality.

Another set of field experiments, undertaken by Vincent (1924), showed that for potato crops 12·8 tons of goémon were as efficient as 35 tons of stable manure so far as the nitrogen and potash contents were concerned; for turnips the ratio proved to be $12\frac{3}{4}$ tons of seaweed to 35 tons of stable manure. It would seem therefore that about a third of the bulk is required if seaweed is used, though it must be augmented by superphosphate. It has been proved that when seaweed manure is employed there is a very rapid uptake of the food salts that it puts into the soil. The effect of the manure, therefore, only lasts a short time and the ground must be manured at least yearly. On the other hand a rapid return on the manure is to be desired, a point of view emphasised by Wheeler and Hartwell (1898) when they said: "The wideawake farmer, like the business man, should hope to get his returns as rapidly as possible, in order that he may not lose the interest on the invested capital."

There is no doubt that the rich algal masses of the sea coast provide an excellent manure, but the principal problem, still more or less unsolved, is the compression of the voluminous mass into a form which can readily be transported. The mechanical division of dry seaweeds usually presents difficulties, and if it is ashed first the valuable nitrogen content is largely lost: it would mean, at all events, that the ash could only be sold as a potash manure.

Although it is evident that quite a considerable body of information exists about the composition of seaweeds as a manure and their effect on the chemical composition of the soil, we know nothing about their effect on the physical properties. It is true that Macdonald (1811) said that the gluten (algin) consolidates and binds sandy soils and after some years improves the staple, but we need to know more than this, and it is obvious that there is here an important field of research that has yet to be invaded.

Red Algae as Manure. Apart from the brown algae, certain of the red seaweeds which produce lime (calcium carbonate) are

used in some areas for a special purpose. These particular red seaweeds belong principally to the genus *Lithothamnion*, and they always grow submerged in the water. They are used on the French coast where they are known as "maerl", whilst a coralline sand, produced from the same species by intensive wave action, is found in Connemara (Ireland), where it is regularly utilised. These seaweeds are of special value because of the high calcium carbonate content (up to 80 per cent), and they are therefore usually employed instead of ordinary lime in order to "sweeten" humus-rich acid or peaty soils. In France it is again transport costs that prevent such material from being used more widely. The action of the maerl is slow if it is used in the form of lumps and in order to get the best results it should be finely ground.

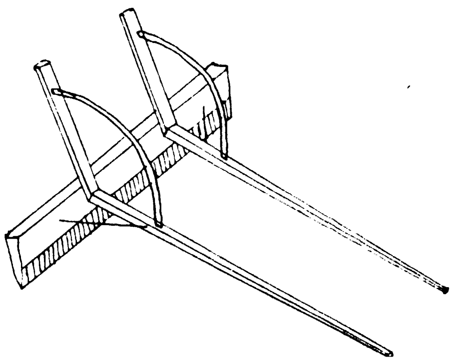


FIG. 29. Rake used in collecting 'maerl' (After Pierre)

Pierre (1853) gives a detailed account of the maerl industry, which is largely confined to Brittany. The main areas in which operations are carried out are at the mouths of rivers; thus, in 1853, the biggest collection was at Regneville. The first reference to maerl was apparently in 1186, when Richard du Hommet, in the interests of the salt works at Mont St. Michel, forbade his people to take "tangue" (as it was called) at St. Germain-sur-Ay. A further reference is made in a map dated 1192, whilst another map of 1331 shows that certain roads to the shore have taken their name from this calcareous deposit, e.g. Chemin Tangoour de St. Pair. About 1200 Liceline, daughter of Hascouf de Soligny, gave to the monks of Savigny the right of working in her tanguiere: "Dedi et concessi in perpetuam elemosinam, liberam penitus et quietam, in tangaria mea, tangam praedictis monachis in usus hominum suorum de vacua valle."

The Coralline sand or mud is collected either by dredging or digging, or by the use of a special rake called a "havel" (Fig. 29). The method of employing the tangue depends on the nature and quality of the mud, the nature of the soil, the proximity of supplies and the type of crop involved. The local peasants used to make compost heaps consisting of alternate layers of tangue and farmyard manure. The tangue or maerl acts on the soil mechanically and chemically, but it is not necessary to apply it every year. Fields growing lucerne received a dose every second or third year, whilst it was only applied every third or fourth year to pasture meadows.

Since this account was written by Pierre little appears to have been added, and if only from the historical aspect, this particular subject would probably repay further investigation.

Fresh-water Algae. So far we have considered only marine algae as food for the land. During the recent war years it was suggested (Polunin, 1942) that fresh-water algae could be similarly employed. It is well known that considerable quantities of planktonic algae have to be removed at certain seasons from reservoirs and other bodies of water. Whilst such material would no doubt form a good manure, its restriction to certain seasons would limit its value. The removal of the plants would also mean the removal of their contained salts, which would not then be liberated through decay and so be available for succeeding plankton crops. Removal of the plankton might therefore bring about a gradual decrease in the plankton each successive year, until finally it would cease to be worth removal.

CHAPTER VII

SEAWEED AS FOOD—II

FROM the point of view of the human consumption of seaweeds or seaweed foods the world can be divided into two major regions. One, the European–American area, includes all Europe, South Africa, and both the Atlantic and Pacific coasts of North America. The other, which can be called the East Asiatic–Indo–Australasian area, includes Japan, China, Malaya, Australia, New Zealand and the South Sea Islands. It will be convenient to consider these two regions separately, and we will commence with Europe and America.

Europe and America. Chlorophyceae. Among the green algae the sea lettuce or green laver (*Ulva lactuca*) used to be eaten, chiefly in Scotland, as a salad, but it has also been used in soups. The eminent French algologist Sauvageau prepared such a salad and he wrote (1920) about it as follows: "It was leathery and waxy in taste, and in spite of a good digestion I thought I would be ill." One must evidently have a cast-iron constitution before attempting this food! In the first world war Phillipsen (1915) prepared a salad with plants of this species and of the related genus *Enteromorpha*, together with the more delicate green plants of another related genus, *Monostroma*. He flavoured it with salad cream, vinegar, lemon, pepper, onions and oil, and then he described it as "wonderfully nice, slightly piquant, and not inferior to the best garden salad". No mention is made about its effect on his health! One also wonders whether he could even taste the seaweeds with all the added flavourings!

Phaeophyceae. Among the brown seaweeds the young stipes or stalks of the sugar wrack (*Laminaria saccharina*) used to be eaten in Scotland, and a hundred years ago they were sold, according to Greville (1830), by fishermen in the streets of Edinburgh, when the old cry "Buy dulse and tangle" was then still to be heard. The present author has eaten these and likes them immensely; there is certainly a sweet taste but they remind one most of peanuts. The same flavour is found in the reproductive leaflets or sporophylls of murlins or badderlocks

(*Alaria*). Apart from the actual raw weeds there was a composite jelly prepared from *Laminaria saccharina* and *Chondrus crispus* and called "Pain des Algues" or seaweed bread, that used to be made on the coast of Armorica. More recently Weiss (1941) and an anonymous writer (1944) stated that the Germans collected and used algae in Norway, where they erected two bakeries in order to make "bread" of dried, ground and desalted algae. It is also recorded that the Indians in Alaska made soups from the giant kelps of the Pacific coast of America, but they ate the raw sporophylls of *Alaria fistulosa*, the stringy kelp, just as the people used to in Scotland.

Rhodophyceae. Similarly among the red seaweeds there are a few which have been used for food. One of the more important of these is *Rhodymenia palmata*, known as dulse or water-leaf in Scotland and as dillisk, dillesk or crannogh in Ireland. The last name is apparently restricted to the smaller and more delicate younger plants. The alga is chewed fresh or after drying, and although Greville (1830) reported that he ate it with pleasure, it is probable that most of us would find it leathery, particularly the larger plants. Another and more favourite method of preparation was to boil the seaweed in milk or oil of citron, and the product was then said to be delicious. Dulse has been employed in Iceland, where it is known as "sol", since the 8th century, and it was a regular article of commerce between the coast dwellers and the people of the interior from the 12th to the 19th centuries, but now it is only occasionally used on the south coast of the island. In old days it was eaten along with dried fish, butter and potatoes, and in times of famine was even baked into bread: indeed, in 1700, it was so highly esteemed that the regulations of one school prescribed it as part of the menu for the pupils. It was also washed and dried, and then put up into small rolls to be used as a kind of chewing tobacco. It is said to be used for similar purposes to-day in Alaska, whilst reports say that in some of the countries bordering on the Mediterranean it is used as a flavouring in soups.

Laver. The thin delicate red seaweed, *Porphyra* or laver, is still a culinary dish in certain parts of South Wales, Devon and Cornwall. It is eaten either as a salad or, more usually, is cooked and made into a breakfast dish. I have only eaten it on one occasion and then it was overcooked and tasted somewhat insipid. In the 18th century it was strongly recommended as a suitable dish for crews of whaling boats. It requires to be fried

in a great quantity of fat and is therefore hardly suitable when fat is rationed. Yarham (1944) reports that the miners of South Wales are the biggest laver eaters, and that laver is still to be seen on sale in Cardiff.

There are numerous local methods of preparing laver, but the usual procedure is more or less as follows:* It is first of all washed well in fresh water in order to remove the sand, and then, after steeping in fresh water for three to four hours, it is boiled gently until tender. This part of the proceedings should not be overdone or else all the flavour will be lost. The water is poured off and a little salt is beaten into the pulp. It can then be served by mixing with oatmeal and frying in the form of flat-cakes, or it can be mixed with vinegar or lemon juice, a few drops of olive oil, pepper and salt and served cold on toast. This dish is said to taste like a mixture of olives and oysters! Another method of using it is to add some butter, a little gravy, lemon juice and pepper, and heat the mixture in an aluminium saucepan, stirring meanwhile with a wooden spoon or silver fork. When cooked in this manner it should be served hot with roast meat and is said to be the classical accompaniment to Welsh mutton. The sea lettuce, *Ulva lactuca*, can be treated in exactly the same way but is not so nice.

In Ireland the laver, or "sloke" as it is called, is collected in spring and stewed or boiled to a jelly and then kept until required. The Irish peasants principally use it fried with butter. Only the small form of *Porphyra* is used in Ireland because it is regarded as being more tasty. The large form is not collected, except in Mulranny, where it used to be sold to unsuspecting tourists who did not know any better. This seaweed was liked and used so much that considerable quantities were exported from Ireland, the price in 1912 being 2s. a stone. More recent inquiries that have been made showed that it was not being imported into England in 1938, and so the export trade has probably died out.

There are two other red seaweeds that used to be eaten, principally in Scotland. These are "pepper dulse", or *Laurencia pinnatifida*, which is a small tufted bushy plant that grows on rocks about mid-tide, and *Iridaea edulis*, which is also sometimes known as dulse because it is very like *Rhodymenia*: it differs from true dulse by being thicker and brighter red in colour. Sauvageau considered that it tasted better than dulse but it is difficult to believe this statement. The old method of

* A detailed recipe is given in Hill (1941).

preparing *Iridaea* was to pinch it between two hot irons, after which it was said to be delicious. Pepper dulse is extremely pungent and was used mainly as a condiment, though in Iceland it was also used as a kind of chewing tobacco. Sauvageau (1920) records that the special odour and piquant peppery flavour of *Laurencia* is only evident in young plants that are to be collected in winter and spring, and that it has disappeared in the older plants found in the autumn.

Mrs. Griffiths, an eminent British algologist of the last century, pickled plants of *Gracilaria compressa* and she considered that they were excellent. Sauvageau, who appears to have sampled most of these edible algae, also recommended the brown seaweed *Dictyopteris polypodioides* as making good eating. On the whole, however, most people would probably agree with Stanford (1862) when he said: "John Bull, though so truly a man of the sea, does not take kindly to an alginic diet." In the second world war a suggestion (Polunin, 1942) that plankton, or the floating life of sea and lakes which contains many microscopic algae, should be used for human food was not enthusiastically received, and no doubt starvation would have to be imminent before we should consider employing it (cf. p. 30).

The use of seaweeds as food was seemingly to be encouraged by a prophetic note, which, according to Marshall Howe (1917), appeared in the New York *Evening Post* some time in 1913. This said: "It is within the bounds of reasonable expectation that we shall soon see 'Shredded Seaweed', 'Flaked Fucus', 'Desiccated Dulse', 'Predigested Sargassum', 'Puffed Nereocystis', 'Malto-Kelp', 'Cream of Sea-moss', and a score more substitutes for hot cakes and maple syrup, done up in one-pound packages, 'Guaranteed under the Pure Food Laws', and crammed down the throats of a long-suffering and surfeited people." The sequel can perhaps be found in an article by Yarham (1944), who refers to a banquet held a few years previously in Wisconsin. Dehydrated algae were used for this feast and among the dishes were fried seaweed, seaweed purée, roast seaweed and devilled seaweed! One may also note that in Great Britain, just prior to the war, a new custard powder, which was manufactured from brown algae, was put on the market, whilst an apparently similar custard powder is on sale (1946) in New Zealand.

Ulva, *Porphyra* and *Rhodymenia* were all at one time commonly used on both the Atlantic and Pacific coasts of North

America. It is said that Chinese residents of California still collect purple laver, *Porphyra perforata*, and use it for food. Three hundred thousand pounds of dried *Porphyra* were collected in 1929, some of which was exported to China and some used in Chinese restaurants in "seaweed soup". Farlow (1876) records that in his day the coastal dwellers around Boston used to import *Rhodymenia* from Canada for eating. This trade must have been in existence in 1911, because Swartz was able to buy some *Rhodymenia* in the market for her researches, and there is a still more recent reference to the trade in the Bay of Fundy (Wilson, 1943).

A very delectable product, which is sold in North-west America where it is commercially known as "Seatron", is prepared by removing the salt, adding flavouring extracts, and candying portions of the stipes and bladders of the giant *Nereocystis* (bull kelp). This sweet was invented by Dr. Frye, professor of botany in the University of Washington, and it is an excellent delicacy: so much so that the first samples received for exhibition in the New York Botanic Garden Museum never even reached the show case!

Carragheen. One of the more important algal food industries in North America, however, is concerned with Irish moss or carragheen. This industry originated in Ireland and it will be remembered that it was only introduced into America in the 19th century (cf. p. 42). The true Irish moss, carragheen or Dorset weed, as it is known on parts of the British coast, is the red seaweed *Chondrus crispus*,* but the name is often applied in addition to *Gigartina stellata*, which is more channelled and is frequently beset with papillae. Numerous other names have been given to *Chondrus crispus* (and probably also applied to *Gigartina*), e.g. pearl moss, sea pearl moss, lichen, gristle moss, curly gristle moss, curly moss, jelly moss and rock moss, the majority being very expressive of the appearance of the plant. In Ireland the narrow form of *Chondrus* was collected for edible purposes, whereas the wide form was used for preparing a size for dressing manilla ropes and linen. In 1912 Cotton states that Irish moss was being exported from Ireland at £8 10s. a ton. A considerable quantity was still being exported from Eire at the beginning of the second world war, the price in 1939 being £22 10s. a ton. Yarham states (1944) that in 1943 a thousand pounds was paid for the *Chondrus* and *Gigartina* crop in Ireland.

* The name carragheen is applied incorrectly in New Zealand to species of the genus *Gigartina*.

The price for this material had, however, been raised very considerably since 1939 as a result of the war, and was probably of the order of £70 to £80 a ton.

Carragheen is principally used in the preparation of blancmanges and moulds and is often to be seen in "health stores". One way of using it is to soak it in water for ten minutes, and then let it simmer for fifteen minutes in some milk with a flavouring added to taste. It is finally strained into a basin and after adding some honey or sugar is allowed to set. It is said that the addition of cream is an improvement. The gelling properties of the carragheen, which are due to an ethereal sulphate, provide its principal claim to usefulness, because it is somewhat tasteless by itself. If water, with the addition of fruit juice, is employed, instead of milk, a nice fruit jelly is the result. Because of these jellying properties Irish moss was used during the last war in the place of gelatine, which was in short supply. The extract responsible for the gelling is known as carragheenin, and in a general way it is very similar to agar. It has a higher ash content and requires greater concentrations (3 per cent or more) to yield firm gels (cf. p. 115). The melting point ranges from 27°C. to 41°C. for a 3 per cent to 5 per cent gel respectively. Chemically it resembles agar in being an ethereal sulphate with galactose residues joined by 1 : 3 linkages, which seem to be of the α type. The sulphuric acid group, however, is attached to carbon atom 4 and not to C_6. On hydrolysis it yields galactose, pentose and perhaps some glucose, together with 2-ketogluconic acid (Young and Rice, 1945). Like agarinic acid, carragheenin is a cell wall constituent, and is considered to occur *in situ* as a mixture of the sodium, potassium and calcium salts of carragheenic acid.

In an especially pure form carragheen is used in the preparation of ice-creams, as a stabiliser (especially in chocolate milk), in pastries, salad dressings and confectionery; it has also been employed in some cough mixtures and in tooth-pastes, and it was formerly used in America for clearing or "fining" beer,* but according to Howe this last use had been abandoned by 1917. It is interesting to note that *Gigartina angulata* and *G. clavifera* are now employed for this purpose in New Zealand. For trade purposes carragheen is distributed in three grades known commercially as "carragheen naturale", "carragheen depuratum" and "carragheen electum albissimum". The last-named is the

* The carragheenin combines with the tan in the hops and forms a gelatinous mass which absorbs the impurities.

purest product, and is probably used for the preparation of "Decoction Chondri" which is probably the best-known algal pharmaceutical emulsifier. Swartz (1911) refers to an interesting case where carragheen was used for feeding weak calves. Twelve calves at one farm became attacked by a wasting disease, as a result of which nine succumbed. The remaining three were given carragheen, one glass of the jelly in milk for each feed, and they soon recovered. The effect of the alga in this case would seem to merit further study.

Very large quantities of Irish moss are also collected on the coasts of France where it is known as "lichen carragheen" or "goémon blanc". Brittany is the chief region where *Chondrus* is collected, and cutting takes place there from May or June through to September. The annual harvest for 1919 is recorded by Gloess (1933) as being 2,000 wet tons of which 1,000 tons were collected around Finistère alone. This quantity decreased in subsequent years and it was only 200–400 tons in 1932. A certain amount of Irish moss was regularly imported from France into England, the price depending on the quality of the product. In 1939 industrial moss was worth £26 a ton, whilst the extra white hand-picked was offered at £56 a ton.* According to Gloess (1932) some of the best carragheen in France is sold under the trade name of "Blandola".

The principal centre of the Irish moss industry in America is at Scituate in Massachusetts, but there is a factory also in Maine. It is also reported recently (Fraser, 1942; Needler, 1944) that the Maritime Provinces of Canada, and in particular Prince Edward Island, have adopted the industry.

In this part of the world plants are gathered between May and September by hand or by means of special rakes from boats. If the rocks are not scraped too clean at the first harvesting, a second cutting may be secured towards the end of the season. It may be emphasised here that at present we know very little about the life history and age of the majority of the Rhodophyceae: the need to use home-grown supplies in the last war should be a powerful stimulus to initiate research, in order to discover the effect of cutting upon the rate of regeneration. Certain periods may prove more desirable than others for harvesting if a species is not to be exterminated (see addendum, p. 249).

The plants, after gathering, are washed in sea water and dried on the beach, and twenty-four hours later they are again washed

* I am indebted to Mr. Redfern Halsall for this information.

and dried. They are subjected to this treatment three to seven times in all, and the whole process of bleaching and drying takes about fourteen days. Irish moss can also be bleached artificially by sulphur dioxide, but this turns it a uniform pale yellow. If necessary it can be decolorised after the sulphur dioxide treatment by washing with potassium chloride solution. During the last war the National Research Council of Canada carried out experiments with Irish moss. In the report for 1942–43 (Anon., 1944 (3)) a new laboratory method for processing this weed was noted, and the report stated that work was proceeding in order to find a commercial method of preparing a good gelling substance from the alga.

When freshly gathered the *Chondrus* plants contain a high proportion (80 per cent of the fresh weight) of water, but when dry they are hard and horny, and the dried material contains 53–59 per cent of the gelatinous ethereal sulphate, plus 10–15 per cent of salts. As might be expected, a water extract of *Chondrus* therefore contains a number of substances, some of which can be extracted in the cold and some in hot solution (Haas, 1921). The proportion of gelling material in dried *Gigartina* is more variable and ranges from 49–58 per cent, and upon its concentration depends the melting-point temperature (Haas, 1923). The salts control the gelling process, and as they are readily washed out by fresh water, the plants must be protected from rain during the bleaching process, and only sea water can be used for washing purposes. Latest reports (Tseng, 1945*a*) state that there are three companies operating in the United States, and that between them about 500,000 lb. of extract were produced in 1944. This compares with 200,000 lb. for 1939 (Chase, 1942), 219,000 lb. in 1919, and 740,000 lb. in 1902.

Summing up the position in the northern hemisphere one may say that the general use of seaweed as a food dropped out of use in Europe, except perhaps for Iceland, about fifty to a hundred years ago. Thus when general and popular journals, and even scientific publications, state that the people of Scotland, Ireland and Scandinavia eat seaweed, it can be taken for granted that it generally refers to the 19th century. Small quantities are no doubt still eaten but only distress or poverty would bring about a wider use comparable to that of a century ago. The possibility of their use is always revived in war-time, but the great advances in means of communications has meant that food formerly lacking can be sent to the more isolated coastal

districts. The discovery of alginic acid may bring about a recrudescence of seaweed eating (cf. p. 202), though in this case the algae are used indirectly. It has also been said that if seaweeds really had some value as foods then their use would have been retained. This, however, is an aspect that will be examined in more detail later (cf. p. 186).

South Africa. Before we pass to a consideration of algal foods of the Orient, some reference must be made to a jelly that is prepared in South Africa from the red seaweed, *Suhria vittata.* This was employed traditionally for jelly-making by the early Cape colonists, and it is said that they were taught by their Malay slaves, who called the jelly "chinchow". The alga grows in deep rock pools or else on the stems of the "sea-bamboo" (*Ecklonia maxima*), from which it is usually collected. After being thrown up on the beach and exposed to the sun it is bleached white, but it is equally good for jelly-making whether fresh or bleached, wet or dry. The recipe used by the steward of the Cape Natural History Club* is as follows; "Take a handful of the seaweed, wash well and boil to a pulp in three to four pints of water. When brought to the boil leave the lid off for about fifteen minutes to allow the fumes to escape. Then strain through cloth and add sugar, lemon or orange juice, and brandy or sherry to taste. Additional flavouring can be added by using cloves, cinnamon, and lemon peel, but these must be put into a muslin bag and dipped into the boiling seaweed for about fifteen minutes."

East Asiatic–Indo-Malay–Australasian Area. Hawaii. In the East Asiatic–Australasian area seaweed foods occupy a much more important place in the life of the people than they do in the northern hemisphere. Thus the inhabitants of the Hawaiian islands eat large quantities of seaweed, which are collectively known as "limu". The name limu is also employed in Samoa, but in Tahiti and Mangaia the algae are known as "rimu" whilst in Guam they are called "lumut". It is interesting to note that the Japanese in Hawaii apparently do not make much use of the local algae, but import their own products (cf. p. 177) from Japan (Moore, 1944*a*). About seventy-five different kinds of seaweed are used as limu, forty of them being in general use, whilst the remainder are less frequently employed. Reed (1907) gives some indication of the extent to which these algae were used when she says: "Ancient Hawaians probably seldom ate a

* I am indebted to Miss Stephens of the University of Cape Town for this information.

meal without some kind of limu, and even to-day [1907] no Hawaiian feast is considered quite complete without several varieties served as a relish with meats or poi (a paste made from the root of the taro plant)."

The following list contains the names of some of the commoner forms used in Hawaii:

Limu ele-ele (black limu)	=*Enteromorpha flexuosa* or *E. intestinalis*
,, wawae-lole or aalaula (mousefoot limu)	=*Codium muelleri*
,, lo-loa (long limu)	=*Gelidium* sp.
,, koele, etc. (dry limu)	=*Gymnogongrus vermicularis*
,, huna (hidden limu)	=*Hypnea nidifica*
,, kohu, koko, or nipaakai (red limu)	=*Asparagopsis sanfordiana*
,, manauea	=*Gracilaria coronopifolia* or *Gelidium*
,, lipoa	=*Haliseris plagiogramma*
,, hulu hulu waena	=*Grateloupia filicina*

The same plants were often called by different names in the various islands, and some of these alternatives have been put down in the list above.

The first two species belong to the Chlorophyceae, whilst the remainder in the list, except *Haliseris*, are red algae. The most popular forms are limu ele-ele, limu kohu and limu lipoa. None of these algae are normally eaten alone, but they are usually finely chopped up in the raw state and used as a relish in combination with other foods, e.g. the kernels of kukui nuts mixed with salt and limu. Another favourite application is to use them as a vegetable with fish and soya bean sauce. The different species tend to have different culinary uses and they may also require different treatment. Limu kohu, for example, has to be soaked for twenty-four hours before using in order to remove the bitter iodine taste; limu manauea is chiefly employed for thickening chicken broth; limu huna is boiled with squid or octopus; limu fuafua (*Caulerpa clavifera*) and limu lipoa are used as relishes because of their penetrating spicy flavour, whilst limu ele-ele is eaten uncooked. The great American algologist, Setchell, visited these islands at the beginning of the present century and he wrote (1902): "The foreigner, as a rule, hesitates to eat raw seaweed, but when he tries the unaccustomed food he finds a variety of flavours and a relish in some of the species

which amply repays him for his courage in making the attempt." Setchell also found that the taste of a single species depended very largely upon the locality from which it came: plants of one and the same species might even be completely inedible from one locality and edible from another.

As an indication of the extent to which the limu were used, it may be mentioned that the sales in Honolulu alone amounted to about 5,000 lb. annually. The majority of the seaweeds can be dried and they are then kept tied up in leaves. The women, children and the aged separate out the brown *Sargassum* and the red *Gracilaria* from the drift, and they also collect from pools or in quiet waters species of the green seaweeds *Ulva* and *Enteromorpha* and the red seaweed *Chondria*. The young men go out into the rougher waters on the reefs, where they collect *Gelidium* and *Porphyra*, or else they go out in canoes to secure *Gymnogongrus* and *Dictyota*, the former a red and the latter a brown alga, which can be recognised by its regular dichotomous* branching. In some parts of Hawaii the algae were so highly esteemed that they were cultivated in algal gardens. It will be noticed that many of these algae belong to genera that are used in other parts of the world, and this emphasises the fact that although a great number of algae are known, only a relatively small number of genera are of use to mankind.

South America. In the south Pacific in Chile, and especially on the island of Chiloe, the giant bull kelp, *Durvillea antarctica*, and a species of the green *Ulva* (sea lettuce) are collected and eaten extensively by the natives, though not by the white population, in soups and vegetables. Hoffmann (1939) records that this practice was still being followed as recently as 1937. The algae are dried and sold in bundles as salted "cachiyugo": they can be bought everywhere, even in the markets of cities such as Santiago. In South America also the stems of certain seaweeds, probably species of *Phyllogigas*, are chewed in districts where goitre is prevalent, and so they are known as "goitre sticks". There is also a reference (Lagerheim, 1892) to a material known as "yuyucho", which is eaten by the Indians of equatorial America. This is apparently prepared from the blue-green alga *Nostoc commune*.

Australia. Very few algae are used as food in South America and the same is true of Australia. There are, however, several

* The plants have regular bifurcations.

references in the literature to the use of *Sarcophycus potatorum** as a food by the aborigines in Australia. *Durvillea antarctica* was also used as a food by the same people: it was prepared by drying and roasting, after which it was soaked in fresh water for about twelve hours before being eaten. There is some evidence that the brown alga *Sarcophycus* was treated in much the same manner.

New Zealand. In New Zealand the Maoris regularly employ certain of the green seaweeds, and they are said to be very palatable in salads and soups. Moore, writing (1944) on the uses of the New Zealand algae, says that a species of *Porphyra* known as "karengo" is much relished by the Maoris in most districts. It is always prepared by steaming and is used as a delicacy for special occasions. Considerable quantities of dried karengo were even sent to the Maoris serving in the Middle East, where it was reported to be more thirst-quenching on desert marches than chewing gum. *Gigartina* is also used in some New Zealand food preparations, though they may also contain a proportion of *Gracilaria*. It is recorded from New Zealand that seaweed meal prepared from *Macrocystis*, together with milk from a seaweed-eating cow, produced a very striking speed-up in the development of a four-year-old child who, at the beginning of the treatment, was not able to sit up and talk.

China. The use of fresh seaweeds is common among all the coast dwellers of China and Japan, but nowadays the algal products of the latter are more commonly used in both countries. However, a blue-green land alga (*Nostoc commune* or Kê-Sién-Mi) and its variety *flagelliforme*† (Fa-Tsai) are still used by the Chinese of the interior for food. The variety is apparently more or less confined to the north-western districts, e.g. Kansu and Sinkiang‡.

Japan. The principal users of the marine algae as food are the Japanese, who gather the harvest of the wild species from the shore by hand, whilst those from the sublittoral are collected by

* In the earlier literature this plant has usually been called *Laminaria potatorum* or *Durvillea potatorum*.

† This is *Nematonostoc flagelliforme* (Berk. et Curt.), Elen. (Elenkin, 1934), previously known as *Nostoc edule*. According to Lagerheim (1892) *N. ellipsosporum* is also eaten in Central Asia.

‡ This information was obtained through the help of the Sino-British Co-operation Bureau.

divers. Some old stamps of Japan* are reported to show intrepid young girls searching the heart of the waves for these seaweeds and then bearing them proudly to their lord and master, who is seated in a boat or on a bridge of boats.

The Laver Industry. Amanori, or the laver *Porphyra*, is one of the most important edible plants, though the name amanori is also applied to the product made from them. *Porphyra tenera* is the species most commonly referred to under this name, and it is this species that is so widely cultivated. Wild species are also collected and they may include *P. onoi* (Ono-nori), *P. okamurai* (Kuro-nori), *P. pseudo-linearis* (Uruppui-nori), *P. umbilicalis* (Chishima-kuronori), *P. dentata* (Oni-amanori) and *P. yezoensis* (Susabinori). Some writers† refer also to *P. laciniata* and *P. vulgaris*, but these are now recognised as forms of *P. umbilicalis*. There is no doubt that in the past these last two specific names were applied to some of the Porphyras that grow in Japan because they were insufficiently known.

Only small quantities of the *Porphyra* are eaten whilst raw, because it is normally prepared in a standard way and sold in the markets as "Asakusa-nori" or "hoshi-nori". The name is derived from the fact that the *Porphyra* used to be sent to the village of Asakusa for its preparation, though, of course, later other places became involved. Matsui (1916) tells us that the name hoshi-nori should be used for the final product, whilst Asakusa-nori refers to the raw material and Amanori to *P. tenera*. If correct this usage has certainly not been adhered to by the majority of writers on this topic. The final product or hoshi-nori is employed to savour soups or else is eaten as a vegetable. The present writer has never had an opportunity of tasting this culinary dish, but those who have (e.g. Delf, 1943) say that it is somewhat tasteless to the western palate.

The main species grows in bays and near river mouths, but the supplies are usually obtained from cultivated grounds. Thus, the Deputy U.S. Fish Commissioner (H. M. Smith), writing in 1905, says: "The cultivation of *Porphyra* is one of the most important branches of the seaweed industry, and gives to Japan a unique position for, so far as is known, in no other country is this form of agriculture practised. The financial results are quite remarkable, and are surpassed by but few

* Chase (1942) says that they are postage stamps. Such stamps are not, however, recorded in Gibbons' catalogue and philatelists I have consulted have been unable to trace them: they may have been stamps of some other category.

† Even Hoffmann writing in 1939 must be included here.

branches of agriculture, comparing the average yield per acre."

The exact date of the beginning of the seaweed culture is not known, but the practice is quite old and probably began in Tokyo Bay about 1700 in the Genna era. Before that time *Porphyra* grew naturally at the mouth of the River Sumidagawa, but as this river continually brought down gravel and silt, land developed at its mouth and the fresh-water current was diverted farther out into the sea. The resulting increasing extension of the fresh-water influence gradually reduced the crop of *Porphyra*, and so in order to maintain supplies cultivation commenced. Some years ago about 1,000 acres were under cultivation, but in 1901 there were over 2,000 acres, yielding nearly 5,000,000 lb. of dried seaweed. Apart from Tokyo Bay the other large area of cultivation is Hiroshima on the inland sea. In 1936 there were nearly 3,000 fishermen engaged in cultivating 50 square kilometres.

In Tokyo Bay, where the principal culture grounds used to be at Omori, the grounds are prepared in October or November by fixing bundles of bamboo or oak brushwood, known as "hibi", into the mud in places where the water is 10–15 feet deep (Fig. 30*a*). The bundles are prepared on shore during the summer, a particular kind of bamboo known as "moh so" being used, and taken out in a boat at low tide. Deep holes are made for the bundles by means of an elongated conical wooden frame with two long upright handles. This is forced into the mud by the fishermen and the bundle is "planted" in the hole so made, the usual procedure being to arrange the bundles in regular rows and at such a depth that the twigs are well covered by water at high tide. A single "farm" is usually about 120 feet by 7 feet, and contains 500 of these bundles.

It has been found that the spores of the laver germinate best in regions where the water is very salty, but that subsequent growth is best in water with only a low content of salt and where there is much nitrogen, e.g. near a sewage outflow. The bundles of twigs are therefore first planted in areas where pure sea-water floods them. There are millions of spores of laver in the sea water and many become attached to the twigs and germinate. Before this happens, and soon after the twigs are planted, the branches become coated with a mucilaginous blanket of diatoms, which are small minute brown algae, and other small filamentous seaweeds. The spores of *Porphyra* are caught in this slimy blanket, but it has been found that the thickness of the

FIG. 30(*a*). Planting bundles of brush on which laver is to grow

FIG. 30(*b*). Washing laver prior to sorting and cutting
(From Japanese prints after H. M. Smith)

blanket depends on the amount of salt in the water, hence therefore a further need for care in the choice of locality. As the salinity of the water decreases so the coating of diatoms becomes thicker, but if it is too thick the attachment threads of the *Porphyra* cannot reach through to the twig and the plantling drops off. The twigs are therefore planted in areas of pure sea-water, but the cultivators hope that some rain will fall soon after the twigs have been planted. A further complication is caused by the fact that if the twigs are planted too early the coating becomes too thick, whilst if they are planted too late very few sporelings develop.

When the twigs have become covered with a rich growth of young plants they are pulled up and kept for five days in a shady place on land, being covered meanwhile with straw mats in order to keep off the dust. They are then taken out and planted in the maturing ground, which is an area of low salinity near some river mouth. The plants which then grow are large and tender and are picked off at low tide. Operations are commenced in September when the twigs are planted, and the plants are ready for harvesting between January and March, though laver gathered in December is said to be the best; after the harvest the old brushes are removed ready for the next season. This kind of cultivation is quite as complicated as that of any of our land crops and is just as dependent upon certain external factors. For example, changes in the direction of the fresh-water currents may bring about a disastrous failure of the laver crop: on one occasion along the east coast of Izu the loss incurred worked out at £1,200 per mile. Such an effect is known as "reef-burning" and the cause was not discovered until 1905 (Yendo). On very rare occasions reef-burning can be brought about by changes in the temperature of the water and one or two such cases have been recorded.

The best grounds for growing Amanori are in great demand, and so the local governments lease the planting privileges. In Tokyo Bay there used to be five classes of licence, the cost of each depending upon the yield of the ground.

When the plants have been gathered they are washed in barrels of fresh water in order to remove sand and mud (Fig. 30*b*). They are then sorted and chopped up finely and spread out to dry on mats of fine bamboo splints (Fig. 31*a*). Drying used to be carried out in the open, but since 1931 much use has been made of special drying rooms. In this way the plants are made into thin sheets, a uniform size being obtained by means

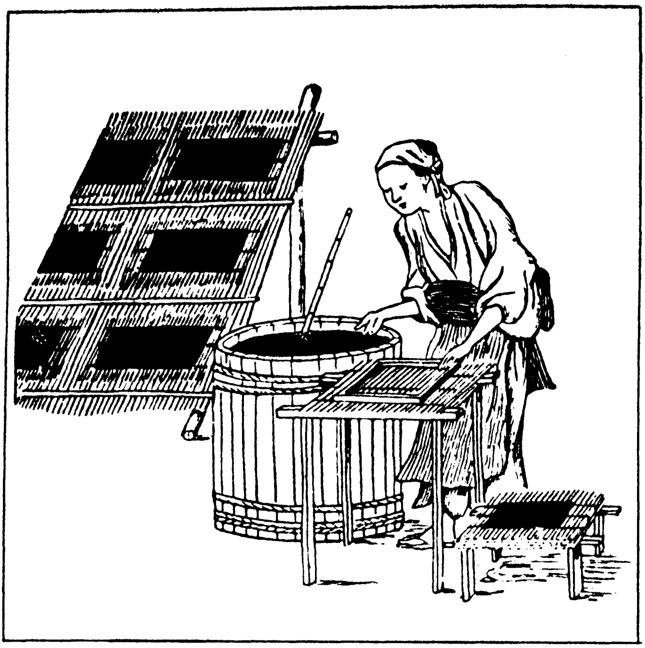


FIG. 31(*a*). Preparing laver sheets.

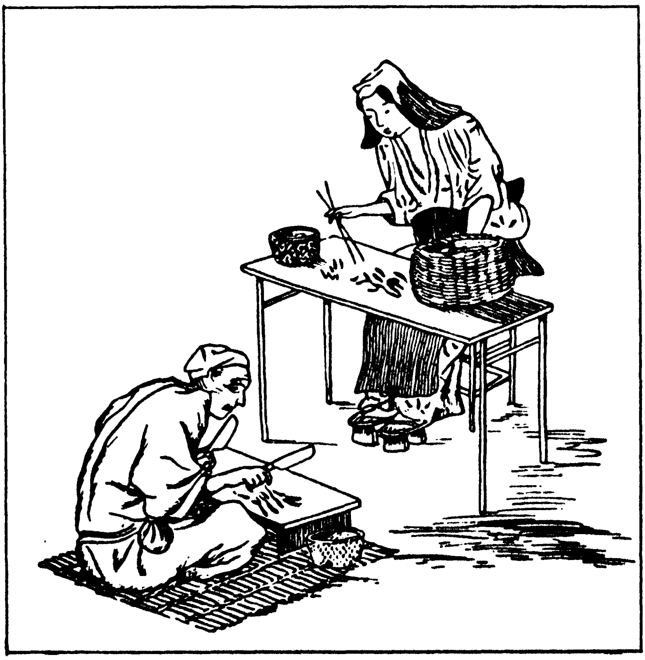


FIG. 31(*b*). Sorting and cutting laver.

(From Japanese prints after H. M. Smith)

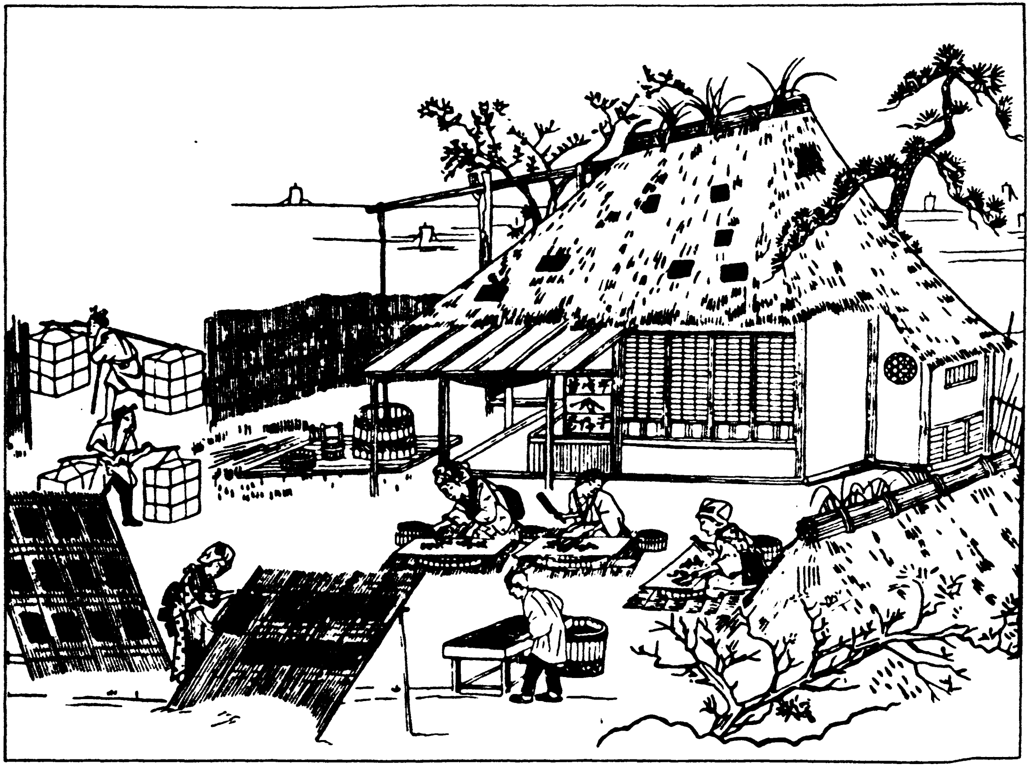


FIG. 32. The preparation of *Porphyra* (From a Japanese print after H. M. Smith)

of a standard frame or mat (Fig. 31*b*). When they are dry the sheets are stripped from the mats and pressed out flat and then marketed in bundles of ten. The sheets are thin and flexible and have a dark, mottled, brownish-purple colour and a glossy surface (Fig. 32).

When the Asakusa-nori, or hoshi-nori, as the sheet material is called, is required for use it is first of all baked or toasted over a fire until the colour changes to green. It can then be broken up and added to sauces, soups or broths to which it imparts a flavour. Sometimes it is just soaked in sauces and eaten. In 1903 it was even being put up in tins after boiling with soya bean sauce. In Japanese railway station buffets, hotels and restaurants it takes the place of the inevitable sandwich, being offered to the public under the name of "sushi". This is prepared by placing boiled rice and strips of meat or fish on a sheet of hoshi-nori, which is then rolled up and cut into slices.

The following figures, taken from Hoffmann (1939), will give some idea of the extent of this industry. In 1913 the industry was valued at £800,000. In more recent years the culture area was 34 square kilometres in 1927 with a yield of 23,827 tons of wet weed, whilst in 1936 the area involved comprised 50 square kilometres with a corresponding yield of 31,540 tons. To this, however, must be added the naturally growing seaweed which is also collected; this wild material is known as "iwa-nori" and in 1936 it amounted to 2,244 tons. In 1936 therefore the total quantity of weed amounted to 33,784 tons and this yielded about 2,750 tons of hoshi-nori. When the delicate nature of the thallus and the small size of the plants is considered, one obtains but a faint conception of the quantity of seaweed that must be required and grown.

Kombu. The other important item of seaweed food in the Japanese diet is called "Kombu" or "Kobu". According to Smith (1904) the manufacture of this product dates back to about 1730, and the methods differ very little from those used in the 18th century. An enormous amount was exported to China and some has been sent to the East Indies. A small quantity was at one time manufactured by the Japanese living on the Pacific coast of North America. In Japan Osaka is the principal centre, with less important ones at Tokyo and Hakodate (Fig. 20). In 1903 there were forty-five factories in Osaka alone, each employing from ten to twenty persons. The seaweeds used for the manufacture of Kombu all belong to the

Laminariales and are collected almost entirely from Hokkaido, the most northern of the main islands. The algae grow in abundance on all parts of the coast, but the best plants are found on the north-eastern coast which is bathed by the cold Arctic current. According to Davidson (1906) nine (Miyabe, 1904, records twelve) different species of *Laminaria* are collected (none of them found in Europe), together with *Alaria crassifolia* or "Chigaiso" (a Pacific relative of the European badderlocks) and two species of a genus, which has not yet been mentioned, called *Arthrothamnus*. In appearance this last genus may be said to combine the characters of *Laminaria* and *Alaria*. The first species is *A. bifidus* or "nekoashi-kombu" (Fig. 33), and the second *A. kurilensis*, or "Chishima - nekoashi-kombu". The number of species of *Laminaria* is probably less than those listed by Davidson because some of the names he gives, e.g. *L. diabolica*, *L. longissima*, cannot be traced in subsequent algological literature and may, therefore, be synonyms or may even refer

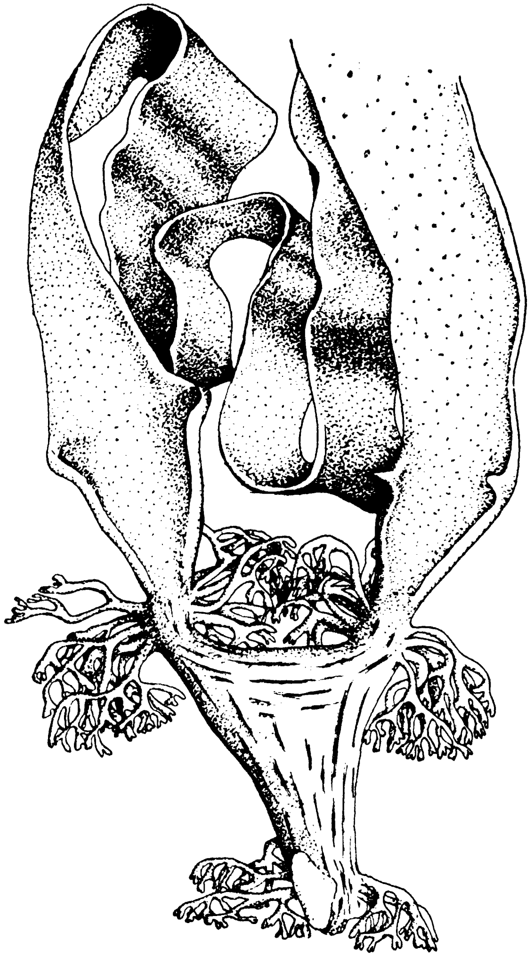


FIG. 33. *Arthrothamnus bifidus* (× ½)
(After Okamura)

to other genera.* The principal species used appear to be *L. japonica* (Makombu = *L. ochotensis* in some of the literature), *L. religiosa* (Hosome-kombu) and *L. cichorioides* or Chizmi-kombu.

* Both these species were apparently described by Miyabe (1904) but few later workers refer to them. Very recently Nagai (1940, Journ. Fac. Ag. Hokk. Imp. Univ. **46** (1), 69) has recorded *L. diabolica* (= *L. longipedalis*), Ohi-kombu, and *L. angustata* var. *longissima* (= *L. longissima*) Naga-kombu, from the Kurile Islands.

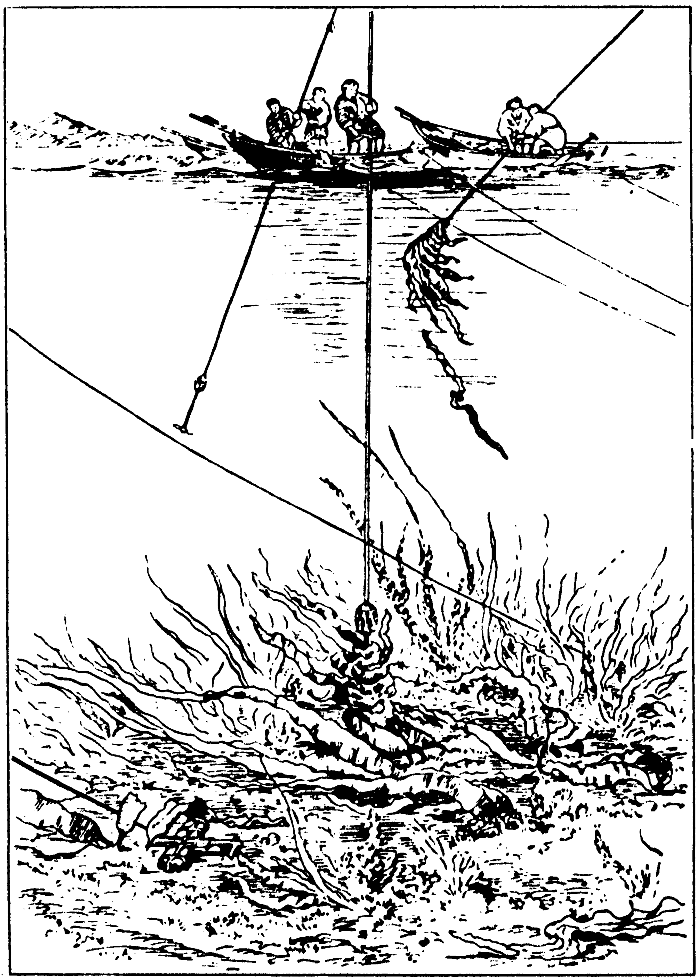


FIG. 34. Gathering kelp with poles and grapnels
(From Japanese print after H. M. Smith)

The gathering of the kelps, which begins in July and terminates in October, is carried out from open boats. Hooks of various sorts on long handles, or weighted and attached to ropes, are used to tear or twist the weed from its home on the rocky bottom.

The pictures (Figs. 34 and 35) illustrate the different kinds of hooks employed and demonstrate how the fishermen go about their task, twisting the weed around the hooks and then pulling.

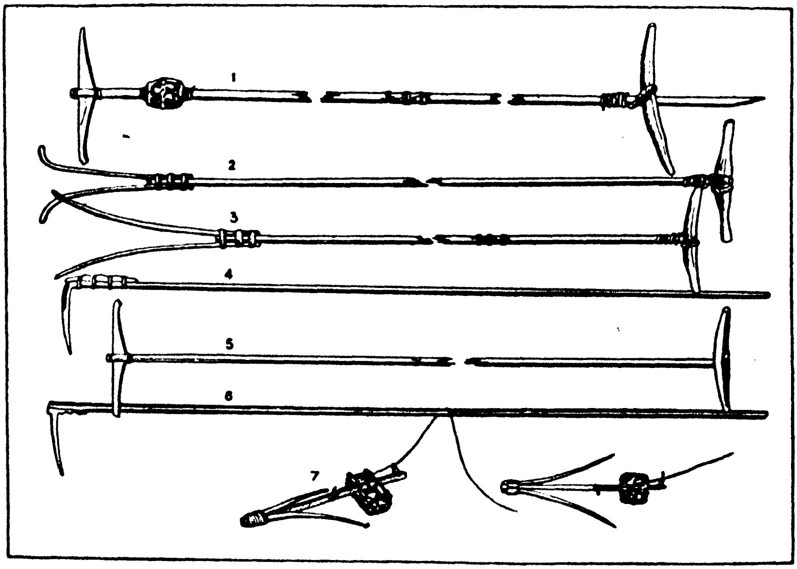


FIG. 35. Forms of hooks used in gathering kelp in Hokkaido
(From Japanese print after H. M. Smith)

This is a very primitive method of collection, and when it is remembered that great quantities of the same algae are also collected for the iodine industry we may well wonder how the fishermen manage to harvest it all. This method also commonly results in the wrenching off of the holdfast so that no regeneration is possible. Cutting near the base of the blade might result in larger harvests because a new blade grows more rapidly than a new plant. This, however, would only be true if the present harvest is about the maximum.

There is some evidence that the harvest from wild sources is not adequate because in some places the kelp is even cultivated. Sandy ground below five fathoms, where there is no wave action

that would disturb the sporelings, is made suitable by the planting of stones. Ten fathoms is usually the maximum depth for cultivation because these algae do not often grow below that depth. In order to secure the greatest possible surface the size of the stones is such that they would just not be washed away when the plants on them are fully grown. Mature plants offer a considerable resistance to the currents and if the stones are not heavy enough plant and stone are both swept away. The stones are usually laid down at the time of year (September) when the plants are reproducing so that the spores will settle on the stones at once. The type of rock composing the stones is also important: andersitic or basaltic rocks are best because they possess minute cavities in which the young spores can settle. Sandstone is not a good substrate for *Laminaria* because when the plants become large the rock is not sufficiently resistant and the plants are torn off if wave action is vigorous. The best growth of *Laminaria* is actually found in places where rocks are scattered in the sand, because then the competition for light between the plants is not too severe.

The plants are dependent upon light for the manufacture of their sugars which provide food for growth; the incident light is already cut down severely in its passage through the sea water because of absorption, so that when it is reduced still more by mutual shading the plants do not grow so well. Sometimes the *Laminaria* beds become invaded by a marine phanerogam* called *Phyllospadix*, and when this happens the beds have to be weeded, a special tool being used for the purpose.

When the kelp has been gathered it is spread out carefully on the beaches in parallel rows to dry. When quite dry the stipe and rooting portion are cut off, and the fronds are tied in bundles, each bundle containing about 50–70 lb., and sent to a factory. At the factory the kombu is treated in one of several ways, one of the commonest being the preparation of shredded ("Kizmai") or green ("Ao") kombu. This is carried out as follows: the dried algae are immersed in boiling water in large iron or copper vats containing a strong solution of the aniline dye, malachite green. Formerly salts of copper used to be employed, but because of their poisonous properties their usage has been forbidden for a long time. The function of the dye is to impart a uniform deep-green colour to the product. The algae are boiled for 15–20 minutes with occasional stirring and then are

* The phanerogams include the conifers and flowering plants. *Phyllospadix* is a flowering plant.

drained and hung out in the air to dry. When the surface of the kelp is dry they are rolled up and sent to women who unroll them and lay them out flat in long wooden frames. When the frames are filled the weed is tightly compressed by means of four cords. These piles may weigh up to 125 kilograms and they are cut into four equal parts, each portion being held together by one of the cords. These smaller bundles are put into presses and when the press is full the bundles are sprinkled with water, in order to make them adhere better, and then they are compressed by means of levers, wedges and ropes. Finally one of the sides of the press is removed and the mass is shredded by means of a plane, though when the industry first commenced the shredding process was carried out with a sharp knife. The shavings are laid out on mats and dried in the open air until the surface is dry when they will still contain enough moisture to keep them pliable. The kombu is now ready for packing, and in this state it will keep for a year or two without deterioration. For local use it is made up in paper packages, but for export it is put up in boxes or tins.

From the thicker species, especially *Laminaria diabolica** ("Oni kombu"), other and finer preparations are made. If the description is followed carefully, it will be realised that the various grades simply represent successive steps in the treatment of a single sample. The frond is first soaked in weak wine-vinegar until it is quite pliable. This imparts a flavour and no doubt has a preserving effect. It is then drained and dried and the blue-green surface layer is scraped off from both sides, leaving the thick white core of the frond. The pieces scraped off are called "Kuru-tororo" or black pulpy kombu, which is often inferior in quality because it also contains sand and dirt. If the shredding is continued with a saw-edged knife a white stringy mass, known as "Shiro-tororo" or white pulpy kombu, is produced. Instead, however, a sharp-edged knife may be used to obtain thin and delicate filmy sheets, which are known as "Oboro" or filmy kombu. The remaining middle thin pieces of the alga, which can no longer be cut up thus, are pressed together with other similar pieces, divided into lengths and planed down as in shredding green kombu. The shavings are like a coarse hair, and so it is known as "Shirago-kombu" or white hair kombu.

* This species, though given a circumstantial Japanese name by Davidson (1906) and Miyabe (1904), does not occur in current Japanese algal literature nor is it mentioned in De Toni's Sylloge Algarum (cf. p. 170).

Fronds of the thinner species of *Laminaria* (e.g. *L. japonica* (Fig. 36)), from which black kombu has first been prepared, are later cut into small pieces of various shapes, e.g. strips, squares, circles, etc., and dried over a fire until they become quite crisp. Such pieces are sold as "Hoiro" or dried-on-the-fire kombu. They can also be coated with white or pink icing when they are called "Kwashi" or sweet-cake kombu. Another method of treatment is to grind the dried pieces into a fine, greenish or greyish powder. According to Davidson (1906) *L. religiosa* is especially used for this purpose. The product is known as "Saimatsu" (finely powdered) kombu, and it can be compressed into small cakes which are often coated with sugar. There is also a form of kombu which is known as tea or "Cha kombu". This is prepared in the same way as green kombu, but as the shavings are cut a second time they are similar to rolled tea leaves.*

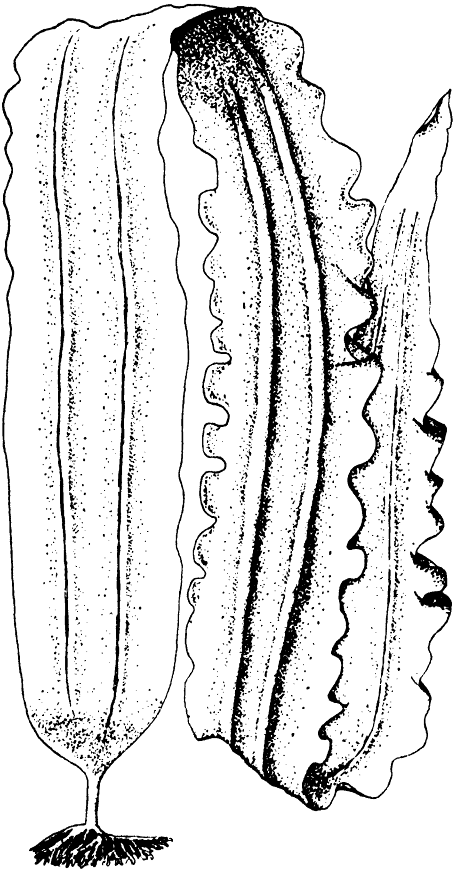


FIG. 36. *Laminaria japonica* (reduced, after Okamura)

The various kinds of kombu find different uses in cooking. According to Davidson (1906) many of the dishes made from kombu are palatable, even to European tastes. Gloess (1919), on the other hand, expresses the very opposite view, because he

* Other forms of kombu are "Dashi kombu" (stock kelp), "Hayani kombu" (quick boiled kelp), "Aoita kombu" (green flat kombu), and "Sosei kombu" or crude kelp as used for fertiliser or iodine manufacture.

says "the different kombus are not to our taste—perhaps because they are not sufficiently pure or because we are unaccustomed to them—for the rest '*de gustibus non disputandum*'!" From this it would appear that no generalisation can be made: some Occidentals may like them, others may not. Green kombu is boiled with meat, fish and soups and is also used as a vegetable. Powdered kombu is employed in sauces and soups or is added to rice in the same way as curry. These two forms, together with tea kombu, are also used for making a tea-like liquid. If any of these products are taken too frequently they cause debility, although they have been prescribed for the treatment of goitre and some diseases of women.

The amount of kombu used in Japan is as much now as it was at the beginning of the century, though about half the total yield is exported to China. Hoffmann (1949) quotes Japanese statistics which show that the weight of *Laminaria* collected for kombu between 1934–36 was as follows:

1934.	475,316 tons yielding 57,087 tons of trade product.
1935.	333,423 tons yielding 52,057 tons of trade product.
1936.	293,284 tons yielding 48,044 tons of trade product.

Gloess (1919) estimates that the huge quantity of one million tons of kombu was gathered in 1901, but in view of the later figures given above this seems very unlikely. These data will provide some idea of the enormous quantities of kelp that are handled each year by the Japanese, but as it is most unlikely that they can collect all the available seaweed, the figures will serve also to give some faint inkling of the tremendous quantities that compose the forests of the sea that surround the Japanese islands (cf. p. 245).

A species of *Laminaria* at first ascribed in the literature to the European *L. saccharina** is also used in Japan to yield a material known as "Kan-Hoa". The same edible product is used in China, where it goes under various names, e.g. Hai-Tai, Kouanpon, Hai-Hoûan, Yan-tsai, or Chai-tai. It differs very little from kombu and is prepared by first washing the alga, after which it is dried and cut up into fragments.

Wakame. Another food product used in Japan is known as "Wakame". The seaweed from which this is made is a large brown one called *Undaria pinnatifida* (= *U. distans*, Miyabe,

* The species in question is closely allied to *L. saccharina*; it may be *L. japonica* or *L. longipes*, but in another capacity it has been referred to as *L. bracteata* (cf. p. 213).

1904), and it is about 40–50 centimetres long (Fig. 37). It grows on rocks in places where there is a strong current of water and at depths of 20–40 feet. It is collected between February and June by means of long-handled rakes, the weed being torn

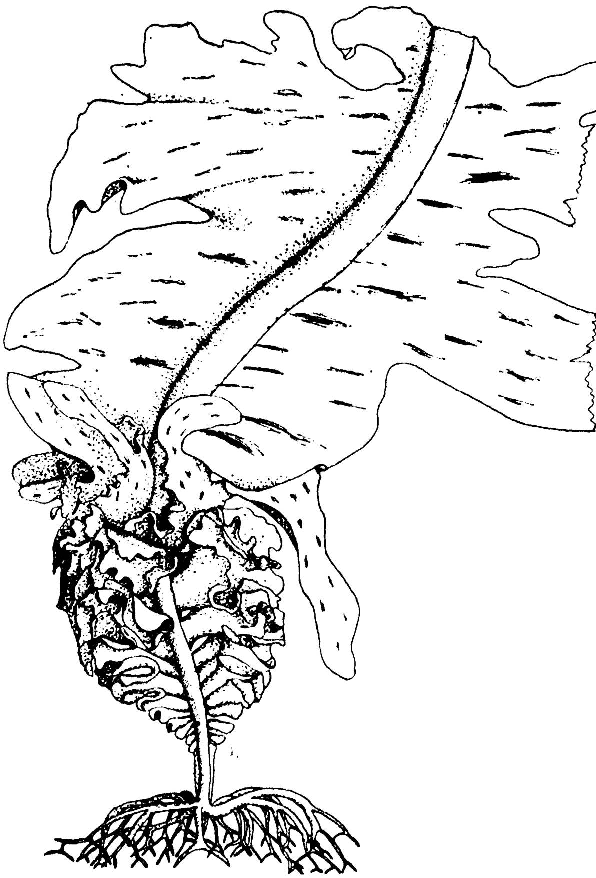


FIG. 37. *Undaria pinnatifida* (× 0.7) (After Okamura)

from its attachment by a twisting motion. The subsequent treatment is very simple as it only involves drying and baling. Sometimes, however, a rather more complex method of preparation is employed; the alga is first washed in fresh water and dried and then re-soaked in fresh water and the mid-rib removed. When the leafy parts are half-dry they are kneaded together and

dried out rapidly. The dried seaweed can also be cut up into short lengths and sold as "Kizami-wakame" or wakame chips. In the province of Shima the chips are tinned, after being coated with sugar, and are then known as "Ito-wakame". In northern Japan the ripe fronds, that is those bearing the reproductive organs, are cut off and compressed into a slimy liquid which is mixed with boiled rice and eaten. The thick rooting portion has been given a different name and is known as "Mehibi"; this is also dried and then cut or shaved into slices and eaten with sauce. Large quantities of this seaweed, which is a member of the Laminariales, are collected annually. In 1936, 44,600 tons were collected, and from them 8,969 tons of finished product were produced.

Other Japanese Food Products. So far we have been considering those Japanese seaweeds that provide trade products, but there are a number of other species which are used in home consumption, and are therefore prepared by the householders themselves. They are employed for making jellies or as condiments, or else are eaten as vegetables and salads. "Arame" (*Eisenia bicyclis*) (Fig. 38), besides being used as an agricultural fertiliser, is also eaten as an ingredient of soups or mixed with soya-bean sauce. "Hijiki", or *Hijikia fusiforme*,* is a brown seaweed that grows on the rocks near low-water mark. It is collected from January to May, the best period being the first two months of the year, when the plants are small and tender. It is dried in the sun and later used after boiling in fresh water.

"Awo-nori" or "Ohashi-nori" is the collective name given to various large species of the green seaweed genus *Enteromorpha*. These grow at the mouths of rivers, where they are subject to the alternating influence of fresh and salt water. In some places they are even cultivated by placing bundles of twigs in suitable localities. The crop is harvested during the winter and spring and is preserved by drying in the sun. For eating it is gently heated over a charcoal fire and powdered: it is used primarily as a condiment. "Aosa" or "Awosa", the sea-lettuce (*Ulva lactuca*), forms a garnishing for meats and fish and is also used in salads. The related species, *U. pertusa* or "Ana-awosa", is probably sometimes used as well. A red seaweed, also utilised as a garnishing, is known as "Ogo-nori" (*Gracilaria confervoides*), but this one is usually first treated with lime-water

* Sometimes referred to as *Turbinaria fusiforme* or *Cystophyllum fusiforme*.

N

FIG. 38. *Eisenia bicyclis* (× 0.6) (After Okamura)

or dipped into hot water in order to change the colour from purple to green.

"Miru" is the collective name given to species of the green genus *Codium*, e.g. *C. fragile* (Miru) and *C. divaricatum* (Kiru-miru). The plants grow near low-water mark on the beach and are collected in April and May, and when they have been dried

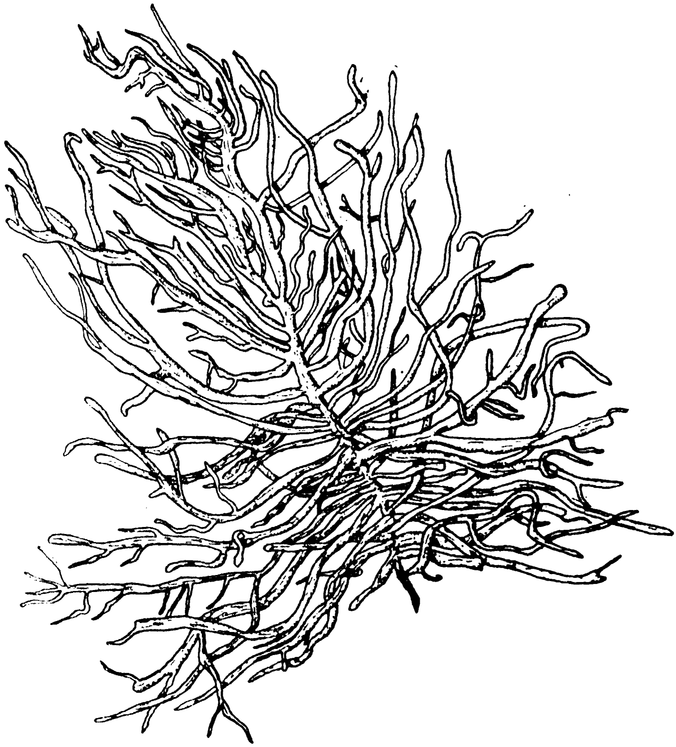


FIG. 39. *Mesogloia crassa* (× 0.7) (After Okamura)

they are preserved in ash or salt. For culinary purposes they are boiled in water and put in soups, or alternatively, after washing in water, they are mixed with soya-bean sauce and vinegar. A thin brown leafy seaweed looking very like *Porphyra* and known as *Phyllitis* (*Ilea*) *fascia* (this also grows in Europe) is treated and used like Amanori. Another brown seaweed is the slippery, gelatinous *Mesogloia decipiens* or "Mozuku" (Fig. 39). This is gathered in April or May whilst young and preserved by salting. It is also used in soy-bean sauce or, after the salt has

been washed out, in vinegar.* Young plants of *Sargassum enerve* ("Hondawara") are also eaten in soup or soy-bean sauce.

It will have been observed already that there are a very large number of seaweeds that the Japanese use to flavour their favourite dish of soy-bean sauce, but the list is still not complete. It would seem that the Japanese require these algae in order to counteract their otherwise excessively proteinaceous diet. A small brown alga called *Heterochordaria abietina*, which looks like a spray of fir (hence its name *abietina*, meaning like *Abies* or the fir), is very abundant in northern Japan where it is known as "Matsumo". It is preserved by packing in salt and is cooked with soy-bean sauce. A somewhat curious use is also found for it in the preservation of mushrooms. The mushrooms are first washed in salt water and are then packed in barrels in layers alternating with layers of the salted matsumo.

Reverting once more to the red seaweeds there is "Umi-sômen" or *Nemalion vermiculare*,† a small slimy species 5–12 inches long, that grows on rocks, being specially abundant in San-in, Hoku-ruku and the north-eastern districts. The related species, *N. multifidum*, is known as "Tsukomo-nori". They are both preserved by drying or by mixing in salt or ash. Like many of the others they are eaten in soup or with vinegar and soy-bean sauce. The crest-like seaweed *Eucheuma papulosa*‡ or "Tosaka-nori" grows on submerged reefs at depths of eight feet or more off the island of Kozu and along the provinces of Ize, Shima and Higo. After storms in August and September it is thrown up on the beaches, when it is collected and dried for use as a condiment or in soy-bean sauce. It is also collected by divers from depths down to ten fathoms.

Irish moss occurs on the shores of Japan, where it is known as "Tsunomata". Another name recorded in the older literature is "Hosokeno-mimi", but there is apparently no evidence of this name being used by the later Japanese writers. The species involved is not *Chondrus crispus*: tsunomata proper would seem to be *C. ocellatus*, but there are two other species, *C. arma-*

* It is possible that the related species, *M. crassa* or Futo-mozuku, is also used.

† Smith (1905) refers to *N. vermiculare* as "Somen-nori" and mentions *N. lubricum* (Umi-somen) as a further species. According to De Toni (1889) this latter species does not grow in Japan nor is it mentioned by Okamura (1906) or Takamatsu (1938). The Japanese authors refer to *N. vermiculare* as "Umi-somen", and the name "Somen-nori" does not appear to apply to an algal species. It may refer to the product obtained from them.

‡ Smith (1904) refers to this plant as *Kallymenia dentata*.

tus ("Toge-tsunomata") and *C. elatus** ("Naga-tsunomata"). The plants after collection are dried in the sun: they are then boiled in order to make a jelly, which can either be eaten as a food or else form a starch for use in laundries.

There are a number of other Japanese red seaweeds which are also dried and eaten in various ways. These include "Tori-ashi", "Yuikiri" or *Acanthopeltis japonica*; "Cata-nori" or "Shikin-nori" (*Gigartina teedii*, which also occurs in Europe); "Kome-nori"† (*Carpopeltis flabellata*), which is first immersed in hot water when it turns bright green and is then used for garnishing fish dishes; "Mukade-nori" (*Grateloupia filicina*, also European); "Makuri-nori" (*Digenea simplex*); "Yego-nori" (*Campylaeophora hypneoides*); "Okitsu-nori" (*Gymnogongrus flabelliformis*) and "Hosaka-nori" or "Atsubanori" (species of *Sarcodia*). In spite of all these numerous seaweeds and the great quantities that are collected, it is somewhat surprising to find that they only form about 0·5 per cent of the total vegetable food of Japan.

On the adjacent continent, in Cochin China, there is apparently only one reference to an algal food. This mentions the use of the red alga *Griffithsia corallina*, which is eaten with sugar after it has been bleached, compressed and cut up.

Indonesia. There is still one more important region in the world where seaweeds have been or still are used extensively for food and that is the Dutch East Indies. In this part of the world they are usually eaten raw or else after being plunged into boiling water for a minute. They may be eaten with a sauce of allspice, or used with sugar or eaten as a relish, for which purpose they are cooked in sugar obtained from palm trees or soya beans. The different species cannot be very highly esteemed, because they are only eaten when the rice harvest has been poor and the price of rice has risen. The coast dwellers probably use them in small amounts at all times.

There are seven regions where quantities of these seaweeds may be harvested, and it has been suggested, though with no

* Davidson (1906) refers to *C. elatus* as "Kotoji-tsunomata" but Takamatsu (1938) uses this Japanese name for *Gymnogongrus pinnulatus*. On the other hand Takahashi and Shiragama (1934) refer to *Chondrus elatus* as "Tsunomata". It is possible that the usage of these names varies in different parts of Japan.

† Hoffman (1939) and other earlier writers give "Kome-nori" as the Japanese name for *Grateloupia affinis*. The Japanese plant is now known as *Carpopeltis affinis* according to Japanese algologists, and they quote the corresponding indigenous name as "Matsunori", Kome-nori referring to the species *C. flabellata*. It is probable that both Matsunori and Kome-nori are used.

real evidence, that there is some relation between these places and the force of the sea currents. The seven regions are:

1. Archipelago of Spermonde to the west of Macassar.
2. The shores of the eastern Celebes (islands east of Salabangka).
3. The eastern coast of Ceram.
4. The coasts of Boeton, Moeno and the island of Galidoepa.
5. The meridianal coast of Bali (of dancing-girl fame) and Lombok.
6. The Archipelago of Riouw.
7. The islands near Batavia.

In the following list, taken from Tondo (1926), of some of these seaweeds it will be observed that many of them belong to genera that are also used as food in Europe, Hawaii or Japan.

Latin name	*Type of seaweed*	*Native name*	*Place*	*Region (See above)*
1. *Turbinaria* sp.	brown		Bangka	6
2. *Sargassum* sp.	brown	bebojot	Lombok	5
3. *Gelidiopsis rigida*	red	sangan?	Lingga	6
4. *Sarcodia montagneana*	red	bebiroe	Lombok	6
5. *Gymnogongrus javanicus*[1]	red	?	Bangka	6
6. *Gracilaria lichenoides*	red	doejoeng	Lingga	6
7. *Gracilaria taenoides*	red	doejoeng djanggoet	Bangka	6
8. *Corallopsis minor*[2]	red	boeloeng	Bali	5
9. *Hypnea cervicornis*	red	boeloeng djadja	Bali	5
10. *Laurencia obtusa*	red	sangan?	Lingga	6
11. *Acanthophora spicifera*	red	boeloeng bideng	Lombok	5
12. *Caulerpa laetevirens*	green	boeloeng	Bali	5
13. *Caulerpa peltata*	green	lata	Bangka	6
14. *Caulerpa racemosa*	green	lelato	Lombok	5
15. *Caulerpa racemosa* var. *clavifera*	green	lai lai	Ternate	Batjan Is.
16. *Codium tomentosum*	green	soesoe lopek	Lombok	5

[1] Tondo places this species in the genus *Gracilaria*.
[2] *Corallopsis salicornia* is a synonym.

It is interesting to notice that the name "boeloeng" is more or less confined to the island of Bali, whereas the name "sangan" is apparently confined to Lingga.

Burma and Philippines. Not far away, on the mainland of Asia, in Burma, *Catenella nipae*, collected on the Tenasserim coast, was regularly on sale in the markets of Rangoon (Post, 1939), where it was used in salads after boiling water had been poured on it.

In the Philippines, especially in the north (Luzon), seaweeds are also boiled and mixed with vegetables, whilst in the island of Guam (cf. p. 158) some of the gelatinous forms are used for making blancmanges.

Nutritional Value. We have now surveyed the areas in which seaweed is eaten, and the remainder of this chapter will be

Seaweed	% *Water*	% *Raw protein*	% *Fat*	% *Starch sugar*	% *Fibre*	% *Ash*
Nostoc commune f. *flagelliforme*	10·6	20·9	1·2	55·7	4·1	7·5
Enteromorpha compressa	13·6	12·4	53·0		10·6	10·4
E. linza	13·5	19·3	1·73	46·2		19·2
Ulva lactuca and *U. fasciata*	18·7	14·9	0·04	50·6	0·2	15·6
Laminaria spp. (av.)	23·5	5·85	1·15	41·95	6·7	21·1
Arthrothamnus bifidus	24·4	5·8	0·7	45·6	6·4	17·0
Undaria pinnatifida	18·9	11·6	0·3	37·8		31·3
Hijikia fusiforme (av.)	16·1	9·9	0·5	56·9		16·9
Porphyra tenera[1] (Amanori) (av.)	17·1	28·0	0·8	40·1		10·3
Gracilaria coronopifolia	12·85	7·9	0·05	58·4	3·0	17·8
Ogo-nori (*Gracilaria* spp.)[2]	—	4·3	—	24·3	4·3	3·55
Yego-nori (*Campylaeophora*)	—	13·65	—	32·2	12·25	3·0
Chondrus crispus (av.)	16·1	11·23[3]	2·59	54·78	2·38	14·2

[1] Tressler incorrectly uses the names *P. vulgaris* and *P. laciniata*.
[2] Probably mainly *G. confervoides*.
[3] According to Haas *et al.* (1923) the percentage of nitrogen in Carragheen ranges from 1·0–2·08 per cent.

devoted to a discussion of the nutritional value of these seaweeds, because this must be regarded as an important aspect in view of the amount regularly eaten in the Orient.

The principal components are carbohydrates (sugars or vegetable gums), small quantities of protein and fat, ash, which is largely composed of salts of sodium and potassium, and 80–90 per cent of water. The abridged table (page 183) from Tressler (1926) gives the composition of a certain number of the edible seaweeds.

Proteins. From this table it can be seen that apart from *Nostoc* (a gelatinous blue-green alga that is eaten in China), Amanori and *Enteromorpha linza*, which all have high nitrogen contents, the food value must lie principally in the carbohydrates. Even in the case of the three species which do have a high nitrogen content it is not known how far the nitrogen is soluble and therefore available for digestion. A further source of error in the figures for raw protein may be due to the fact that they were obtained by taking the average value for total nitrogen and multiplying by 6·25, on the assumption that the material consists of a protein with 16 per cent nitrogen. Konig and Bettels (1905) give some figures, reproduced below, for the solubility of the nitrogen, but they do not say how far the soluble products can be utilised in digestion.

	Wakame	Arame	*Enteromorpha*	*Hijikia fusiforme* (av.)	*Laminaria japonica*	*Porphyra tenera* (av.)
% Water-soluble N. substances	5·31	7·50	5·5	3·89	5·44	21·85

The problem of the nitrogen utilisation of these algal foods had not been experimentally tested up to 1939 and it is impossible therefore to make any further comment. It is, however, evident that *Porphyra* is really protein-rich, and tests should be made to ascertain how much of the protein can be digested. The nature of the protein also requires to be studied because some are much more digestible than others. In Japan, according to analyses of Okuda and Nakayama (1916), it would seem that the price of asakusa-nori or hoshi-nori runs more or less parallel with the protein content.

Price in sen of 100 grams of dry asakusa-nori ..	75	53·8	53·9	77½	68	55½
Protein content ..	5·05	4·25	3·7	5·65	5·55	4·8

Matsui (1916) also claimed that the market price of hoshi-nori reflected the value of the contained food materials, but this is certainly not borne out by all his figures.

Pentegow (1929) gives some detailed figures for the composition of Japanese algae used in the manufacture of kombu, and these have their interest because they are more recent and the methods of analysis were probably more refined.

% Composition (water excluded)

Species	*Locality*	*Protein*	*Fat*	*N.-free subs.*	*Fibre*	*Ash*
L. angustata	Ezan	6·48	1·16	52·72	7·21	32·41
	Hakuro	7·04	1·82	63·63	4·88	22·62
	Mitsuishi	8·10	1·99	60·15	6·55	23·19
	Urakawa	7·55	1·61	63·54	5·24	22·06
	Horotzumi	6·44	3·24	68·68	4·98	16·65
	Kunashiro	7·05	1·95	56·84	6·49	27·66
L. longissima[1]	Kujiro	8·32	3·06	47·94	7·61	33·51
	Ochiishi	8·26	1·3	42·98	8·59	38·87
	Hanasaki	10·71	2·68	38·63	9·81	38·16
L. japonica	Ofudgun	6·44	2·06	61·15	7·57	22·27
L. cichorioides	Tomomale	9·2	1·56	60·09	6·70	22·44
	Rijivi	9·85	0·91	53·65	8·63	26·95
	Tsunashiro	8·3	1·42	53·89	7·49	28·82
	Menashi	7·51	0·60	55·40	8·95	29·05
L. religiosa	Fukugama	6·11	1·06	55·46	13·2	24·16
L. fragilis	Muroran	5·26	0·85	52·52	9·3	32·07
Arthro. bifidus	Kujiro	7·71	0·97	60·31	8·52	22·48

[1] Probably a variety of another species of *Laminaria* (cf. note p. 170).

The variations in protein content of one and the same species from different localities is very striking, whilst the values for fat content show even greater variation. The locality of the material is therefore of very considerable importance. *L. longissima* differs from all the other species in having a much lower content of the nitrogen-free substance (carbohydrates mainly), but this is perhaps compensated to some extent by the high protein and fat.

Carbohydrates. When we turn to consider the digestibility of the sugars and starches, an attempt must be made to distinguish between the different kinds of carbohydrate, because like the proteins some are more digestible than others. If a seaweed contains 50 per cent of carbohydrates it does not follow that all of it is available as food. On the other hand, those carbohydrates classed as pentosans are readily soluble and hence can be regarded as digestible. All the seaweeds in the list above (p. 185) contain from 4 to 11 per cent of pentosans.

Oshima (1905) considered that about two-thirds of the total sugars could be digested. His experiments, however, lasted for too short a time and were not sufficient in number. Another Japanese, Saiki (1906), came to the conclusion that carbohydrates were not attacked to any extent by digestive juices, and that under a quarter was absorbed. In his experiments he employed raw algae and common Japanese algal products, e.g. kombu, asakusa-nori. In addition to the failure of the digestive juices to attack the foods, Saiki found that bacteria had little effect upon them.

A similar conclusion was arrived at some years later by Swartz (1914). In the meantime Lorisch (1908) had carried out experiments in which a man was fed on soluble agar: under these conditions he was found to use about 50 per cent of the carbohydrates, which were probably mainly reducing sugars. The utilisation of pentosans and galactans in algal foods was confirmed to some extent by Swartz (1914), as the following table shows, and the complete utilisation by the man in the case of

Material	*Seaweed*	*% utilisation*	
		Dog	*Man*
Pentosan	Dulse (*Rhodymenia*)[1]	73 (2)[2]	100 (2)
,,	*Enteromorpha*	35 (2)	9 (2)
,,	*Ulva*	—	34 (1)
,,	*Haliseris pardalis* (brown alga)	16 (2)	—
Galactan	Irish moss (*Chondrus*)	33 (2)	6 (2)
,,	*Gracilaria coronopifolia*	33 (2)	30 (3)
,,	*Hypnaea nidifica* (red alga)	56 (2)	10 (1)
,,	*Ahnfeldtia concinna* (red alga)	—	60 (1)

[1] According to Colin and Guéguen (1930) the sugar of *Rhodymenia* is a complex of glucoside and galactose which they call Floridoside. This exhibits a regular seasonal variation with a maximum in the summer and a minimum in winter. Further work on these sugars is evidently desirable.

[2] The figures in brackets refer to the number of experiments.

dulse is outstanding. Apart from this exception the amount of carbohydrate absorbed is very low. In Swartz's experiments the algae were administered in the form of attractive jellies or blanc-manges.

In many of the experiments quoted above people unaccustomed to a seaweed diet were used, and in view of the success obtained with horses after a period of conditioning (cf. p. 132), it is possible that better results would have been reported if the persons undergoing the trials had been on a seaweed diet for some time previously. Oshima's results may perhaps be accounted for partially in that he used Japanese subjects for his experiments, and they were probably accustomed to eating seaweed. Another valid criticism that has been put forward is that the experiments did not last for a long enough period. An interesting point is raised by the last example in Swartz's group because the subject had chronic constipation, and in his case 60 per cent of the material was utilised. A similar result was also obtained by Lorisch (1908), and there was also the case of the effect of seaweed on a poorly developed child (cf. p. 161). Undernourished animals have also been found to succeed better on a seaweed diet than well-fed animals. There would therefore seem to be a definite indication that seaweed foods are of more value to sick animals and persons than to those in normal health.

Nothing is known at present about the fate in the human body of the carbohydrate laminarin (cf. p. 219), which is abundant in the oarweeds at the time of year when they are collected for the manufacture of kombu, and it would seem desirable that some research should be carried out on this subject. Gloess (1919 and 1932) thinks of kombu only in terms of the algin (cf. p. 192) which it contains, but there again there is little or no information concerning its utilisation.

If there is no food value in the nitrogen and carbohydrates of algal foods because of their indigestibility, it has been suggested (Oshima, 1905) that some food value may exist in the mineral salts, and in this respect they may play some part in the control of deficiency diseases (cf. p. 145). Swartz (1914) and Perrot and Gatin (1912), on the other hand, adopt the view that the roughage of the algae compensates for the one-sided rice and fish diet. The value of agar in human diet is also largely ascribed to roughage. This interpretation, however, does seem to be too narrow: it would appear, from the evidence available, that dulse, amanori and kombu may have some food value,

mainly on account of the carbohydrates they contain. There is little doubt that further experimental work is necessary, and future digestion experiments should be accompanied by a simultaneous estimation of the energy metabolism.

It is perhaps worth noting that seaweeds are usually employed as a food only in countries that have a low living standard because they are poor, or else in periods of famine.

Iodine and Goitre. There are, however, other aspects which require consideration. For example, the use of algae and algal products in the Orient is regarded as the principal reason for the lack of goitre. This may have been achieved unconsciously, but on the other hand it does represent a real contribution to national health. The incidence of goitre in Japan has been placed at one in a million; this is probably due to the iodine that the algae contain, and analyses have been carried out in order to determine not only the iodine content but also the state in which it occurs (cf. p. 66). According to Okuda and Eto (1916) the iodine appears to be present in the fresh plants in an organic form, but in the preparation known as "Dashikombu" the iodine has apparently been changed into the inorganic form. They suggest that the change is due to the action of micro-organisms, but the experimental data offered is not convincing, and although they refer to further experiments the results are not published. It will be remembered (cf. p. 65) that western workers have concluded that iodine in algae used for kelp manufacture is largely present in the inorganic form. The species in Japan are, however, different and further study is certainly necessary.

With regard to the actual content of iodine, McClendon (1933) found that Laminariaceae used in the preparation of kombu have high values, e.g. *L. japonica* contained 0·07–0·45 per cent of its dry weight and *L. religiosa* 0·08–0·76 per cent. Among the edible green algae *Codium intricatum* (Motsure-miru) contained a considerable quantity of iodine, 0·13–0·16 per cent of the dry weight, whilst red algae such as *Gelidium* and *Grateloupia* contained a medium amount. The Chinese have also carried out some analyses of the iodine contents of the principal algae used as foods, but the results of independent investigators show a wide divergence (cf. *Digenea* in table below), and it is evident that reliable data have yet to be obtained. The following table is taken from Tang and Whang (1935).

Alga	I_2 *in parts per million of the dry material*
Gloiopeltis furcata . .	53
Hijikia fusiforme . .	320
Digenea simplex . .	260 (2,000 according to another source)
Ulva lactuca	31
Gelidium amansii . .	1,600
Laminaria religiosa . .	240 (11,580 according to another source)
Porphyra tenera . .	18

It is perhaps worth noting the very low iodine content of the *Porphyra*.

Vitamins. There is, however, the possibility that the algae may be valuable as sources of vitamins. Vitamin A is found in the sea-lettuce (*Ulva lactuca*), *Laminaria digitata*, in *Codium tomentosum* and in kelp meal from Pacific coast kelps, the quantity in the first-named being comparable to that found in cabbages. Vitamin A is also extremely abundant in plankton diatoms. Ahmad (1930) has shown that the diatom *Nitschia* is extremely rich in this material, and as it forms the food of fishes he suggests that this alga is probably the source of vitamin A in fish-liver oils. From this point of view the use of plankton as food (cf. p. 153) could be strongly recommended. Vitamin B is found in sea-lettuce (*Ulva*), *Alaria valida*, *Laminaria* species, *Porphyra nereocystis*, *Wildemannia perforata*,* *Rhodymenia pertusa* and in kelp meal from Pacific coast algae. In the case of vitamin C as much is found in some seaweeds as in lemons: the principal species containing it are sea-lettuce (*Ulva*), *Alaria valida*, and the species of laver mentioned above, together with *P. naiadum*, *Wildemannia perforata* and *Gigartina papillata*. Apart from *Ulva* all these algae are oriental or Pacific species, but for comparison there is the following information from Lunde and Lie (1938)† about European species (table, p. 190).

From these figures it can be stated that, weight for weight, dulse contains half as much vitamin C as oranges, whilst some of the Fucoids and *Porphyra* are even richer. In Greenland the algae, which are eaten raw or dipped in boiling water or eaten with blubber oil, may be of considerable value because Hoygaard

* Hoffmann (1939) quotes this species as *Porphyra perforata*.

† These data are more extensive than those given by Lunde (1937), and also they show the seasonal variation: thus spring and autumn appear to be the seasons when certain algae are extensively rich in vitamin C.

	Ascorbic acid in fresh seaweed	
	mgms. per 100 grams fresh wt.	
Laminaria digitata	3 (Winter)	to 15 (Spring)
„ *cloustoni* (tangle) ..	10 (February)	„ 47 (March)
„ *saccharina* (sugar wrack)	4 (February)	„ 24 (May)
Himanthalia	28 (Winter)	„ 59 (May)
Alaria esculenta (Murlins) ..	11 (December)	„ 29 (May)
„ sp. (Greenland)	45	
Fucus serratus (black wrack) ..	11 (December)	„ 48 (September)
„ *vesiculosus* (bladder wrack)	13 (December)	„ 77 (September)
„ sp. (Greenland)	13	
Ascophyllum nodosum (knobbed wrack) ..	30 (Winter)	„ 62 (September)
„ „ (Greenland)	11	
Rhodymenia palmata (dulse) ..	24 (March)	„ 49 (October)
„ „ (Greenland) ..	17	
Gigartina mamillosa	26 (February)	„ 63 (May)
Porphyra umbilicalis	44 (February)	„ 83 (May)
Ulva lactuca	27–28	

and Rasmussen (1939) consider that the Angmagssalik Eskimo obtains 50 per cent of his vitamin C from algal foods.

Very little is known about the amount of vitamin D contained in algae, and although it is said to be present there is no satisfactory evidence. Vitamin E is also said to occur in the wracks, but the information is extremely meagre. It would seem that this aspect of seaweed food requires to be studied anew and in much greater detail, especially for vitamins D to G.* The data also suggest that the same species in different localities may vary very considerably as regards vitamin content.

There is no doubt that whatever may be the direct food value of algae they are useful because of their iodine content, which serves as a protection against goitre, whilst the bulk and water prevent constipation. A definite goitre belt runs across England from Somerset to Nottinghamshire, and if the inhabitants of this region could be persuaded to add algal foods to their diet there is little doubt that the goitre would disappear (in this connection cf. also p. 71).

Apart from the algae already discussed, agar is apparently of some value when added to foods. Hoffmann (1939) suggests that it may contain vitamin-like substances, but Mitchell (1922),

* Kelp meal prepared in California is said to contain vitamins F and G (Tseng, 1946).

who worked on this problem, concluded that the roughage it provided was the most important feature. On the other hand it was found that rats fed on a pure synthetic diet showed faulty growth, which disappeared when 5 per cent purified agar was added whilst the addition of the agar also induced breeding.

In conclusion it can be said that the considerable use of algal foods in Japan may be related to the fact that, apart from rice, the Japanese have few vegetables. It is evident that the seaweeds replace them, and their diversity is comparable to the diversity of our vegetables. With the spread of western civilisation, and the greater ease of communication, there is a decrease in the consumption of these algal foods; this has been very noticeable in Hawaii and is beginning to make itself felt in Japan. As Tondo (1926) says:

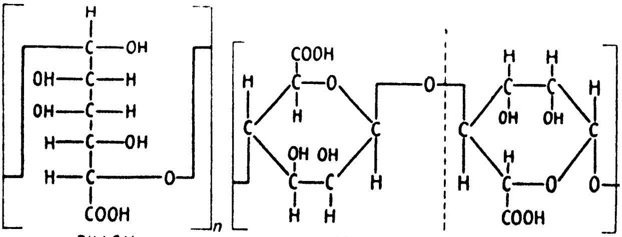
"They will become as old armour, beautiful costumes and beautiful kimonos, for family fêtes to perpetuate the cult of the ancestors; the kombu will be eaten with soya sauce or a cup of cha-kombu will be drunk, or a packet of amanori offered as a rare gift."

CHAPTER VIII

ALGIN AND SEAWEEDS IN MEDICINE AND THE HOME

IN the historical chapter reference was made to the discovery by Stanford of algin in 1883, and it was suggested that the event might prove to be the beginning of a new era in the use of seaweeds. Stanford, who first prepared this substance, did not succeed in obtaining it in the pure state, and because of the impurities he described it as a nitrogen-containing compound. It was later properly prepared by Krefting (1896), who thought he had a new substance which he called "tangsaure", or seaweed acid. Since Stanford discovered algin the name has been applied to a number of substances derived from alginic acid. It has been suggested (Tseng, 1945*a*) that it is desirable to reserve the name algin for the soluble sodium salt of alginic acid, and it will be so used here.

Chemistry of Algin. Alginic acid is a complex organic compound composed of polymers of *d*-mannuronic acid. It is usually given the chemical formula of $(C_6H_8O_6)n$ according to Marsh (1942), Lunde *et al.* (1938), Hirst (1939) and Speakman (1944), or $(C_6H_{10}O_7)n$ according to Dillon (1938), where n is regarded as being some number between 80 and 83. The two formulae differ somewhat and are written as follows:



DILLON   SPEAKMAN, ASTBURY

Speakman and Chamberlain (1944) devote considerable space to a discussion of the correct formula. They declare in favour of the pyranose ring $(C_6H_8O_6)n$, and this has since been confirmed (Astbury, 1945) by means of X-ray analysis. From a

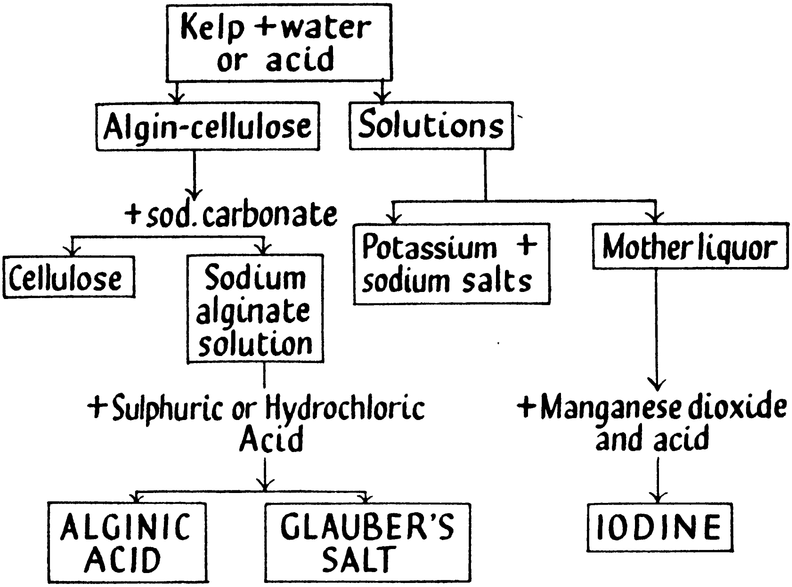
study of the literature the general weight of evidence seems in favour of this structure. The unit, or molecule as it is called, of alginic acid consists of a chain of about 80 small ring units strung together rather like a chain of beads.* The chain arrangement is of the greatest importance, because it helps to provide strength to the molecule and it is also responsible for one of its most important properties, e.g. the power of forming fibres. Chemically, it is interesting to note that in principle the alginic acid configuration can pass over into the cellulose configuration or vice versa by intramolecular oscillation. The interrelations of these complex polysaccharides are therefore of considerable interest.

Production. One of the simpler ways of obtaining this acid is to macerate the seaweed with dilute hydrochloric acid in order to remove any soluble mineral salts: Gloess (1932) regarded the material left after this first treatment with acid as "coarse algin" ("algine brute"). The alginic acid can then be extracted by using a solution of sodium carbonate, during which treatment the tissues swell up and lose their shape. The resulting solution, which is viscous, is filtered, and the algin is precipitated from it by treatment with more acid. The crude material is filtered off and washed, whilst from the solution Glauber's salt can be obtained. Dillon (1938) has described another easy method of preparation as follows: the weed is first extracted for a short time with boiling water in order to remove fucoidin. It is then soaked in dilute hydrochloric acid for a day, after which the alginic acid is removed with ammonia. Wet weed was commonly used for these extractions, but Gloess (1919) considered that the maximum extraction was achieved if the weed were dry rather than wet. Factories, on the other hand, would want to use fresh weed in order to obviate the drying costs, which may outweigh the advantages of using dried weed. The preparation of the pure material is said to be very difficult but it has been achieved on a laboratory scale. Thus, Barry and Dillon (1936) describe a fairly elaborate technique by means of which pure alginic acid can be obtained.

The very first method of production described above is the basis of the "lixiviation process", which was proposed by the chemist Stanford (1884) at the end of the last century, in order to enable the Scottish kelp workers to compete with the produc-

* The molecular weight of alginic acid varies with its mode of preparation. In the case of sodium alginate it ranges from 48,000 to 185,000.

tion of potash from mineral resources (cf. p. 59). The principal stages in the lixiviation process are set out in the scheme below.



Plates 12 and 13 show a washing battery and the drying of the washed algae taking place in a French factory for the production of algin. The manufacture of alginic acid and its salts is at present being carried out by at least one firm in Great Britain and by several in the U.S.A., and there are probably more elsewhere. Gloess (1932) has stated that the Société Otam was producing the purest alginates in France at that time, but production may have ceased in France by now.

No published details of the commercial processes used in England are available, but in America there are two basic processes: Green's cold process (as used by the Kelco Co.) and the Le Gloahec-Herter process, as used by the Algin Corporation of America.

In the first, or cold process,* fresh kelp is first leached for several hours with 0·33 per cent hydrochloric acid. After being chopped and shredded the leached kelp is digested with soda ash solution (40–50 lb. per ton of fresh kelp) at a pH of about 10: this first digestion occupies about 30 minutes and it is then repeated. The crude pulp is shredded again and six volumes of

* So called because it is conducted at the relatively low temperature of 50°F.

treated water added at a pH of 9·6–11. At this point the crude fibrous material can be dried and sold as crude sodium alginate.

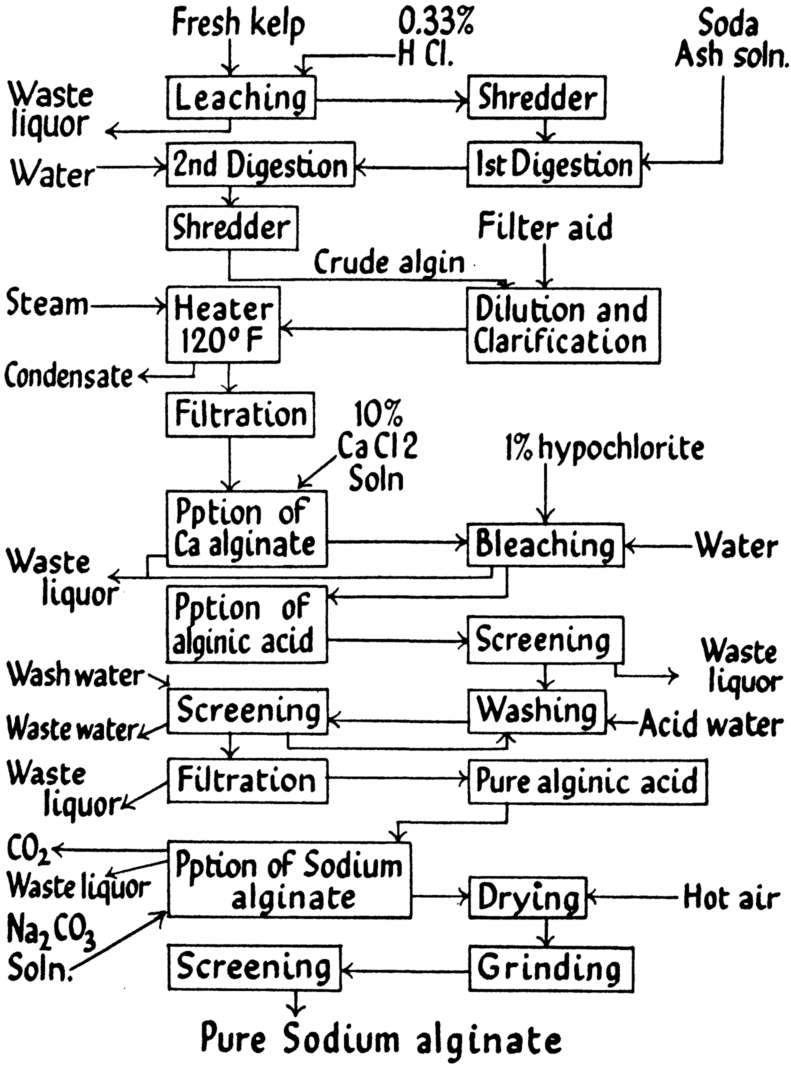
To obtain a purer product the liquor is filtered, using filter aids and presses, and the temperature may be raised to 120°F. to assist the process. The filtered liquor is added to a 10–11 per cent calcium chloride solution under constant agitation, and when the agitation is stopped calcium alginate slowly rises to the top. The remaining liquor is drained off and more water and a bleacher (sodium hypochlorite) is added to the precipitate. Too much bleacher must not be added as it exerts an adverse effect on the final product.

The bleached precipitate is separated off and added to a 5 per cent hydrochloric acid solution (1 part alginate solution to 42 parts acid). This converts the calcium alginate into fibrous alginic acid, which is purified of calcium salts by being passed several times through screens, agitation with dilute acid taking place between each screening. The alginic acid so produced can be filtered and stored or else converted into a salt by treatment with a carbonate, oxide or hydroxide. The process is generalised in the scheme (Tseng, 1945*c*) on page 196.

In the Le Gloahec-Heyter process the raw kelp can be either fresh or dried. To one part of kelp three parts of 0·8–1 per cent calcium chloride solution are added, the solution being either hot or cold. The function of the calcium salt is to remove laminarin, mannitol and other salts. These salts and the calcium are then removed by washing with softened water, after which it may receive an additional treatment with 5 per cent hydrochloric acid in order to dissolve any residual alkaline earth salts. It is washed once more with softened water, and is then digested with 4 per cent soda ash solution in the proportions of two volumes solution to one volume of kelp. Lixiviation is continued for about two hours at 104°F. and the kelp is macerated at the same time until it is reduced to a paste.

The resulting paste is diluted with water in the ratio 3 : 7, and after being beaten into a homogeneous suspension it is vigorously aerated, but if ozone or hydrogen peroxide are used it is merely agitated mechanically. The liquor is then passed continuously at high speed through a centrifuge, where it is charged with air bubbles, and then led into a clarifying tank. Here the cellulose particles agglomerate to form a floating cake and the liquor is removed.

The coloured liquor is decolorised by the addition of an absorbent jelly, usually made of hydrated alumina, gelatinous



Flow sheet of Green's Cold Process

silica and aluminium alginate. The jelly is removed by centrifuging and can be reclaimed by various methods.

The alginic acid is now precipitated by running it into a mixing baffle, where it meets a stream of strong hydrochloric acid, arranged in such a way that the precipitate runs at once into another tank. All through this process the pH of the solution is maintained at 2·8–3·2. The precipitated alginic acid is placed in baskets and drained, after which it is purified and dried.

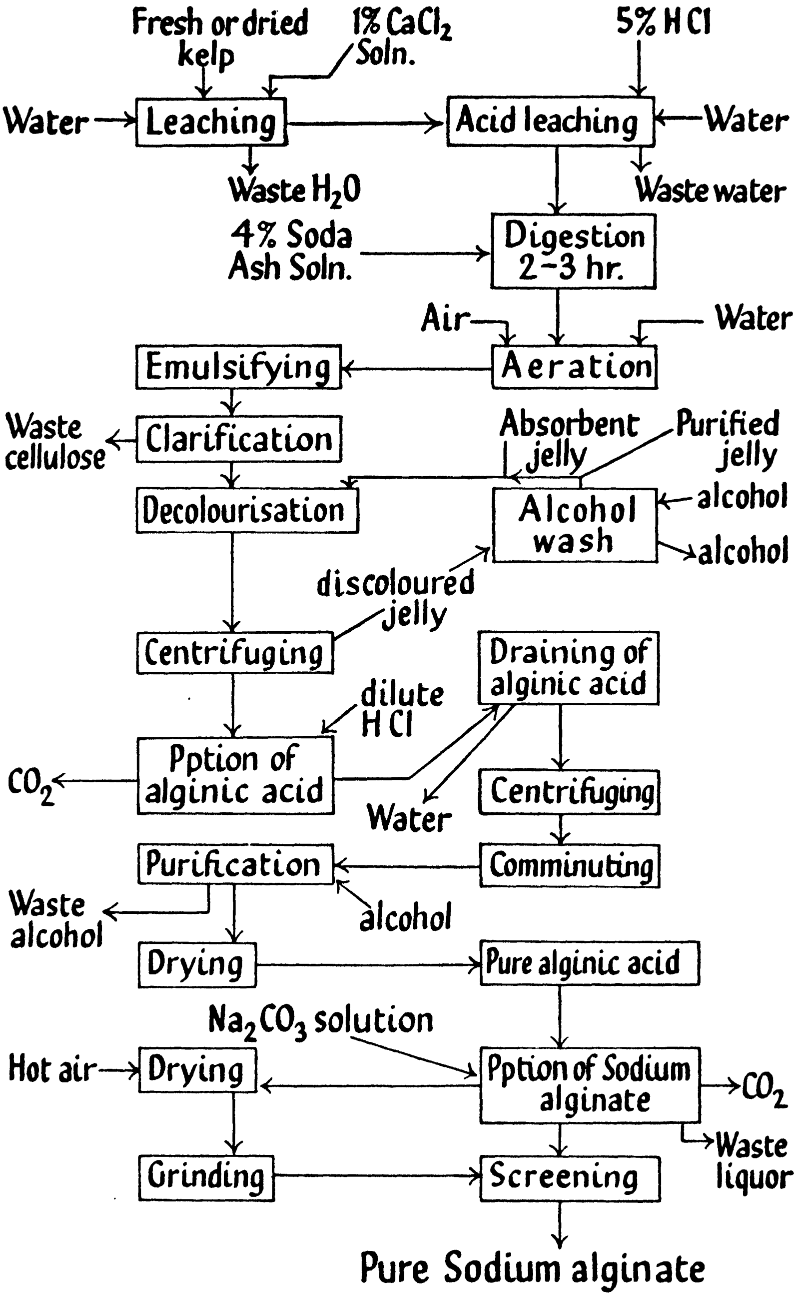
Decolorisation can also be achieved by the use of formaldehyde, tannic acid or other protein coagulants. If formalin is used it is added before digestion with soda ash solution, and after the mixture has stood for one hour the kelp is taken out and kept in a store for 15–21 days. When the soda ash solution is now added, only the alginous matter is dissolved, and the pigments remain behind "fixed" by the protein-cellulose mixture. The flow-sheet for this process is set out in the scheme (Tseng, 1945*c*) on page 198.

According to Tseng (1945*c*) the production of algin in the U.S.A. in 1941 was about two million pounds, the crude product selling at 5 cents a pound and the pure product at 80 cents to $1 a pound. There is reason to believe that in subsequent years the production of algin has greatly increased.

Occurrence. Alginic acid is found in all the larger brown seaweeds, where it is regarded as playing an important part in the composition of the cell wall. A substance allied to algin and called Fucin has been reported from the brown rockweeds but at present very little is known concerning it. The exact state of the alginic acid in the various seaweeds still seems to be uncertain. Bird and Haas (1931) thought that 59 per cent existed as free acid with a smaller percentage present in the form of calcium, magnesium and alkali salts, but Dillon and McGuiness (1931) have produced evidence which suggests that a high proportion of it is combined with colloidal compounds of iron and calcium.

Some idea of the amounts available in certain species is given by the following figures quoted from Lunde (1937, 1938) and his co-workers.

Tangle (*Laminaria digitata*)	15–40%
Sugar wrack (*Laminaria saccharina*) ..	15–35%
Badderlocks (*Alaria esculenta*)	30–35%
Knobbed wrack (*Ascophyllum*)	20–30%
Black wrack (*Fucus serratus*)	18–28%



Flow sheet of Le Gloahec-Herter Process

Bladder wrack (*Fucus vesiculosus*)	..	18–28%
Button weed	..	38%
Button weed (*Himanthalia lorea*)	..	38%
Giant kelps	..	13–24%
Macrocystis	..	14–18·7%

Studies by Ricard (1931) and Lunde (1937*a*) of the amount of algin present in *Laminaria* throughout a year revealed the fact that there was a definite seasonal fluctuation: the algin content reached a maximum between September and November, so that to obtain the best yield the weed should be harvested during

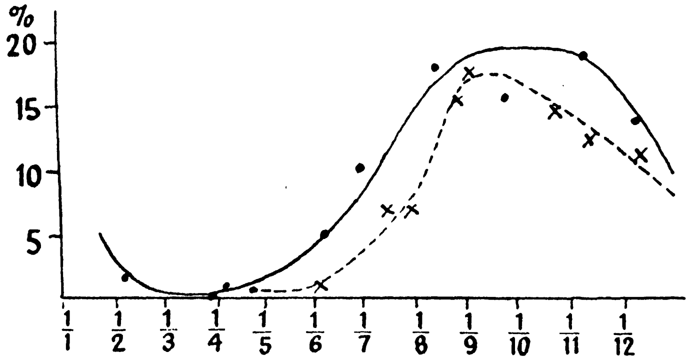


FIG. 40. Seasonal variation of Algin in *Laminaria digitata* (After Lunde)

these months (cf. Fig. 40).* There is also some evidence that the amount of algin in the Pacific coast kelps varies with latitude: the following rather inadequate data for *Macrocystis* from Hoagland (1916) show that plants from the south contain considerably more algin than those from farther north (see addendum, p. 251).

Organ	*Locality*	% *Algin in fresh weight*
Leaf	Pacific Grove (north) ..	1·8
Leaf	San Diego (south) ..	2·7
Stipe	Pacific Grove ..	1·7
Stipe	San Diego	2·3

This result is comparable to somewhat similar phenomena mentioned previously (cf. pp. 77, 185) for iodine, potash and nitrogen. On the whole relatively few analyses for algin content have been published, and it is desirable that this gap in our

* Black (1948) records similar seasonal fluctuations for *L. cloustoni*, but finds that the maximum (24 per cent) is reached in February. It therefore seems that region or locality play some part in determining fluctuations.

knowledge should be filled. Little information, for example, is available about the effect of habitat, e.g. estuary, fiord, loch, upon the content of algin† (see addendum, p. 251).

Collection of Raw Weed. A valuable feature of alginic acid is that it can be extracted from fresh driftweed as well as from cut rockweed. In America the giant kelps are used for the extraction of algin, and for this purpose they are freshly cut by mechanical harvesters (cf. Plate 4), but in Europe both cast and cut weed is employed in the fresh or dry condition. Supplies of cast weed are dependent very largely upon the weather, and in order to overcome this difficulty a patent was taken out in England in 1898 for preserving piles of kelp by means of heavy gas oils, but now sulphur dioxide is used. If sulphur dioxide is employed, Dillon (1938) finds that the alginic acid obtained from it is more viscous than that obtained from fresh material.

One of the principal problems facing all European concerns is the collection of fresh raw material. The production of alginates requires large quantities of weed and therefore mechanical harvesting is almost a necessity. Unfortunately the plants are not large and rarely float on the surface as do the Pacific giant kelps, so that harvesters on the American pattern (cf. p. 79) cannot be readily employed. Apart from the use of cut rockweed collected in large nets and towed ashore, experiments have also been made by a British company with box-shaped trawls for collecting oarweeds. These had fixed cutting knives at the bottom and the cut weed floated into the collecting net. These trawls could probably gather as much as one ton of weed per haul, though the quantity obtained obviously depends on the density of the bed and the length of time the trawl is down.*

The same company also considered the use of cast weed When this is present in quantity it is obviously a very good source of material, but it is important to deal with it rapidly before it decays or the tide takes it out again. With this in view experiments were conducted with an agricultural rotoscythe machine for cutting up the weed. This type of machine might well be a means of overcoming the problem and further experiments are probably desirable (see addendum, p. 251).

Properties of the Salts. Originally algin was not considered to be of sufficient value alone, and the process by which it was

* I am indebted to Messrs. Cefoil (now Alginate Industries Ltd.) for this information.

† Moss (in press) proves that in *Fucus vesiculosus* the algin content is greater in plants from the open sea than in plants from lochs.

obtained was suggested as a commercial necessity, in order to enable the Scottish kelp industry to compete with mineral imports from Chile. Now however the position is reversed and the alginic acid is of greater importance than the kelp salts. From the technical point of view the importance of alginic acid lies in the properties of its salts, although the moist acid itself is of interest because of its capacity to absorb 200–300 times its weight of water! The sodium, potassium and magnesium salts all dissolve readily in water to give a solution that is extremely thick or viscous. Sodium ammonium alginate, for example, is fourteen times as viscous as starch and thirty-seven times as viscous as gum-arabic, and is particularly noteworthy for its acid resistance. These alkali solutions, which are tasteless, odourless and almost colourless, do not coagulate on heating nor do they set to a firm jelly when they cool. The trade product 'Manucol' is primarily a purified form of the sodium salt (sodium alginate).

The heavy metals (e.g. mercury, beryllium, copper, cobalt) also yield salts of alginic acid, but these are not soluble in water. They do, however, form a plastic material that can be moulded when it is moist and which sets hard on drying. This is an extremely useful property with great potentialities. Another property of considerable significance from the industrial viewpoint is the ease with which the soluble alkali salts can be converted to the insoluble heavy metal salts. The numerous patents that have been granted in recent years for processes concerned with alginic acid indicate rapid progress, not only on the technical side but also in our knowledge of its chemical properties.

Uses. The soluble salts of alginic acid are used in the textile industry because they form an excellent dressing and polishing material. A preparation of the sodium ammonium salt, known as Norgine, used to be manufactured by the Norgine company at Aussig in Bohemia, and was regarded as particularly valuable for this purpose. Norgine in the form of a 0·5 or 1 per cent solution provided a softer, fuller and better dressing for materials than any of the ordinary substances commonly used for this purpose. The Norgine factory, however, went into liquidation in 1910.

The soluble alkali salts can also be used as a thickening material for colours that are employed in printing fabrics, and as a hardener and adhesive for joining threads in weaving. Deschiens (1926) has also described how they have been used for impregnating manure sacks. The cementing and filling

property is made further use of in the paper and cardboard industries. Another use for the soluble salts is in the manufacture of briquettes, especially those made from brown coal or lignite, and for this purpose they are said to be markedly superior to other substances. In the manufacture of the briquettes a 2·5 per cent solution is used as the binding medium. Other possible uses are dependent upon the emulsifying power of the salts, e.g. in casein emulsion paints: this property should open up further uses for water-insoluble substances such as tar products, petrol, oil and disinfectants.

When the soluble salts have been converted into insoluble salts, the latter can be used for the production of waterproof cloth such as tents and wagon covers. Ammoniated aluminium alginate is employed in this connection because it becomes insoluble after drying. Because of their pliability whilst moist, the insoluble salts can also be employed in the preparation of plastics, vulcanite fibre, linoleum and imitation leather. Another use has been found for them in the clarification of sugar solutions and mineral waters. Copper and mercury alginates are said to be valuable components of paints for use under the sea because of their insoluble character. This latter application, however, is one that needs confirmation and further study. All the insoluble heavy metal salts can be dissolved in ammonia and when the solution is evaporated a waterproof film is left that can be used as a varnish. Thus Gloess (1932) says that ammoniacal copper alginate has been employed successfully in France for impregnating and preserving wood.

One of the increasingly important uses of algin, especially in the United States, is as a stabiliser to give smooth body and texture to ice-cream. In fact about half the total output in the U.S.A. is applied to this purpose. It is also used as a stabiliser in icings and sherbets where it is replacing agar, whilst it is also put into cream cheeses and into whipping creams for decorating fancy cakes. In the confectionery trade it is used as a filler to candy bars and also in salad dressings.

Another very important use of algin is as a latex creaming agent in the production of rubber from natural sources. For this process it has been found that ammonium alginate is the best salt.

If an alkaline solution of algin, with which a small proportion of tannic acid has been mixed, is violently agitated, the mixture emulsifies and can be poured upon a glass or polished surface to give a thin transparent film resembling cellophane (Pehorey,

1937). The film is cheap, almost non-inflammable, and does not become quite so brittle in light as does cellophane. When algin is mixed with resins or lacquers it yields a rubber- or gutta-percha like product, for which no doubt a number of uses will be found. For this purpose the weed is treated with sodium carbonate, formalin and tan bark to which either rubber, glue or resin is added. The product is said to be a very good substitute for panelling board or linoleum.

A modification of the alginic acid manufacture has been used on a small scale in Galway (Dillon, 1938), in order to produce a hard horny mass which could be used as a wall or ceiling board (Plate 11*b*). In this process the weed is allowed to rot until the algin becomes degraded or else disappears entirely. Acid is then added and the remaining alginates are precipitated leaving a solution of inorganic salts. The precipitated organic matter is finally boiled with alkalis in order to yield the hard horny mass.

A more important potential usefulness for algin can be visualised in the production of an artificial fibre. If the purified alkaline extract is forced through a fine aperture it forms a viscous thread, which can then be spun in a bath containing a mixture of furfurol, caustic soda, formalin and other substances. This process was patented by Gohda and a full account is given by Speakman and Chamberlain (1944) and by Speakman (1945). Marsh (1942) gives a brief description of the various methods that have been patented for obtaining silk threads from algin. One method involves the extrusion of a 7 per cent solution into a bath containing 10 per cent chloride of lime. The Japanese, using alginic acid prepared from a species of *Sargassum*, obtain a 3 per cent solution of the ammonium salt, which is forced through holes and coagulated in a bath containing 10 per cent sulphuric acid. The fibres are subsequently immersed in a 10 per cent solution of aluminium sulphate, and are then given a final bath in a weak solution of lead acetate.

Speakman and Chamberlain (1944) have studied the potentialities of alginic fibres in some detail and have arrived at the following conclusion: "It seems clear that alginic acid fulfils the main requirements of a substance intended for use in the manufacture of fibres. It consists of chain molecules of high molecular weight possessing reactive side chains, and abundant supplies are readily available.* Solutions of the soluble alginates are

* Supplies may indeed be abundant but experience shows that they are not so easily harvestable.

sufficiently viscous for convenient spinning on the viscous system."

Their experiments showed that at present the best solution for the production of an alginic yarn is a 7·5–8 per cent solution of air-dry sodium alginate, of such a grade that the viscosity of a 1 per cent solution at 20°C. is approximately 40 centipoises. For use with this solution there should be a coagulating bath of normal sulphuric acid saturated with sodium sulphate. This gives a thread of sodium alginate, but by passing the thread into a normal solution of calcium chloride in 0·02 N hydrochloric acid a yarn of calcium alginate is secured. Speakman and Chamberlain found that the threads of yarn produced in this way tended to adhere, but they overcame this difficulty with the calcium thread by using 2·5 per cent olive oil emulsified by the neutral detergent Lissapol C; for alginic acid threads other emulsifying agents had to be used.

It has been found that the strength and extensibility of calcium alginate rayons increase with increasing viscosity of the spinning solution. The "handle" of the final product is also improved by increasing the concentration of the spinning solution. The best results were obtained when a liquid was used that contained 7·5–8·0 gm. of sodium alginate per 100 gm. of solution. Improvements in the yarn have also been effected by improved washing and handling techniques, because these are apparently very important items. As originally produced the tenacity of the calcium alginate yarn was low, 1·23 gm./denier* as against 1·3–1·8 for cellulose and viscose threads. This weakness was due to degradation resulting from the carrying over of acid and to mechanical damage. The former was overcome by washing and the latter by winding on to the reel direct from the drier. The tenacity then increased to 1·8–2·1 gm./denier. The breaking load of calcium alginate increases with increasing metal content, but density also increases so that there is an optimum metal content for maximum tenacity at about 10 gm. atoms per 100 gr. of alginic acid (Fig. 41).

Unfortunately threads prepared from alginic acid, sodium alginate and calcium alginate are readily dissolved by soap and soda. Soda alginate is even soluble in water. This fact was largely responsible for the abandonment of much calcium or beryllium alginate fibre produced during the last war for camouflage netting (Tseng, 1945*c*). In spite of precautions the fibre contained sodium alginate as an impurity and the material

* Denier = weight in grams of 9,000 metres.

therefore gradually rotted in a wet climate. Attempts have naturally been made to obtain a resistant fibre, and it has been found that chromium alginate is resistant but is too highly coloured to form a satisfactory general solution.

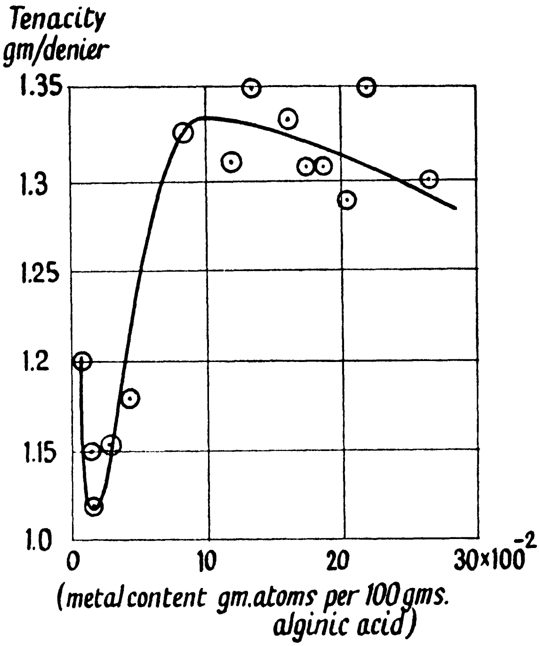


FIG. 41. Optimum tenacity of calcium alginate in relation to metal content

The degradation of ordinary alginic acid threads is relatively rapid, and the tenacity falls from 1·06 grm./denier after 28 days to 0·36 grm./denier after 480 days. Calcium alginate on the other hand can be stored for 30 weeks without any loss of strength. The introduction of chromium or beryllium stabilises the yarn and also makes it alkali-resistant, though better yarns are obtained by introducing these metals into alginic acid direct. Yarn containing 1·29 per cent chromium and 9·04 per cent Ca or 2·89 per cent Be and 5·2 per cent Ca are stable, and suffer less than 5 per cent loss in tenacity after 30 minutes' treatment with soap and soda at 25° or 45°C. The tenacity of beryllium alginate even exceeds 2 grm./denier. A yarn resistant to alkalis can also be obtained by cross-linking with formaldehyde (Speakman, 1945). The discovery that beryllium alginate is resistant

to soap and soda was important because threads prepared from this salt then assumed particular importance. One method of preparing them is as follows: Filaments of sodium alginate are obtained first of all, and they are then passed into an emulsion of sulphuric acid and olive oil, after which they go into a bath of beryllium acetate kept at the temperature of the boiling point of water. In this bath the sodium is replaced by the beryllium.

Speakman and Chamberlain (1944) have improved on this technique. They found that calcium alginate can be woven or knitted, and then converted to an alkali-resistant rayon when in fabric form by treatment with the basic acetates of either beryllium or chromium. It would seem therefore that any large-scale production of a seaweed rayon will depend upon the preparation of a stock material of calcium alginate, which can be converted to a resistant salt later. This method of manufacture is also determined to some extent by the fact that alkali-resistant rayons are difficult to prepare by direct spinning, and also the extensibility of chromium and beryllium alginate is too low to permit of their successful use in weaving and knitting.

The artificial silk obtained by these various methods is of very good quality, and it should ultimately be able to compete with artificial silk made from other sources. Glass dresses have been advertised in the press and there is no reason why seaweed dresses and stockings should not become the vogue! One asset of these threads is that the fibre does not burn so that woven material would be non-inflammable. Yet a further improvement can be foreseen because certain salts of alginic acid are coloured, and hence cloth made of such threads would not require to be dyed; furthermore the colour would be fast and would not come out in the wash. As examples of these coloured salts there are copper and nickel alginates which are green, whilst cobalt alginate is red and chromium alginate is blue. Apart from this the non-coloured salts also have a marked affinity for basic dyes.

During the recent war experiments with alginate rayons have resulted in the production of new fabrics and new effects. Some of the latter are only beginning to be exploited and there should be a great future for the industry. Two examples may be quoted: if cotton and calcium alginate yarns are woven so as to remove the normal twist in cotton, the calcium alginate can subsequently be removed by solution in an alkali thus leaving an untwisted cotton fabric. The "disappearing fibre" technique,

as it is called, has also been used effectively with mohair and calcium alginate.

Other uses for the alginates have also been considered, though there is no evidence that they have been employed. For example, Gloess (1919) has suggested that brick and cement buildings could be coated with a 1 or 2 per cent solution of the soluble alginates, in order to make them weatherproof. It has also been found that dried milk and cocoa can be rendered more soluble, and can also be made without any sediment if alginates are added to the milk, before it is dried, or to the cocoa-powder. Other uses quoted for algin are the production of fire-retarding compounds consisting of chemicals dissolved in sodium ammonium alginate, can-sealing compounds, insecticide sprays and in storage batteries where it is used for separating plates. It also has extensive uses in medicine and dentistry (cf. p. 211), as a binder for printers' ink and in cartridge primers, and as a means of sealing off porous formations in oil-well drilling in muds. When mixed with an inert siliceous material and concentrated oil of vitriol it makes an efficient colour-absorbent for decolorising liquids.

Some of the salts exert an oxidising effect, e.g. sodium peralginate, and so they can be utilised for bleaching and washing. Soap to which the magnesium salt has been added can then be used in hard water or even in sea water. In this connection one may also mention the use of crude algin as a water softener in boilers. It reacts with the scale-forming metallic ions to give an insoluble alginate, which forms flocculent masses that can be blown out of the boiler at intervals.

So far no mention has been made of any uses for alginic acid or alginates in agriculture. The wet seaweed contains much crude algin and there is the further possibility of using the crude salts. Very little work appears to have been carried out on this aspect. Waksman and Allen (1934) have found that the soil contains bacteria (principally *B. terrestralginicum*) which are capable of decomposing alginic acid. This decomposition is significant because in the process a primitive form of lignin is deposited in the soil in a form similar to natural humus. In the plant Waksman and Allen consider that the crude algin is a mixture of alginic acid and this primitive lignin. It is evident that here there is considerable scope for further research. If the above researches are confirmed it means that algin, when put on the soil, will have a considerable effect upon both its chemical and physical properties.

Commercial Firms. Before and during the last war there were two or three companies in America (cf. also p. 194), several in France and one in Norway, all engaged in the manufacture of algin. Gloess (1932), for example, refers to two trade products produced on the continent. The first, an impure sodium alginate, is called "Tiss-tang", whilst the second, "Armorine", is a preparation of ammonium alginate. According to Lunde (1938) the Norwegian factory was not operating in 1938, but during the war the newspapers reported the production of a cloth from seaweed by a Norwegian factory. This must almost certainly have been an alginate product. One firm in Great Britain was engaged extensively in the manufacture of alginates prior to and during the last war.

Alginic acid or its salts were used to some extent in the first world war, and in 1915 a factory was erected at Sydney, in British Columbia, for the manufacture of potash and algin. This factory used 30–40 tons of wet weed daily, but in spite of legislation passed to encourage the industry, it does not appear to have flourished. During the same war alginates of good quality were also prepared in Tasmania from *Macrocystis* and in New South Wales from *Ecklonia*, though for what purpose it is not stated. It has recently been suggested by Isaac (1942) that the large beds of *Laminaria pallida* and *Ecklonia maxima* (=*E. buccinalis*) on the west coast of South Africa might prove a profitable source, not only for algin but also for potash.

Sufficient has now been said about algin to indicate its possibilities and attention must be directed to some other algae and their uses. The opinion may, however, be expressed that any future major algal industry will have to include alginic acid and products in its programme.

Funori. In Japan there is a rather important seaweed glue called "Funori", which is used for adhesives and sizing papers, fibre or cloth. It has been prepared solely in Japan since about 1673, and although much used in that country is scarcely encountered elsewhere. The word "Funori" also refers to the seaweeds from which the glue is made, although the word means "material for stiffening fabrics". The principal seaweed (Fig. 42*a*) is a red alga *Gloiopeltis furcata* (Funori or Fukoro-funori), but two other species are also used, *G. tenax* or "Ma-funori", and *G. complanata* or "Hana-funori".* *Gymnogongrus pinnulatus*

* Some authors refer to *G. coliformis* and *G. intricata*, but these are now regarded as forms of *G. furcata* and are collectively known as Funori. Hoffmann gives "Yanadi-funori" as the Japanese name for *G. tenax* but this is not used by either Okamura (1909) or Takamatsu (1938).

or "Hira-kotiji", and species of *Iridaea* ("Ginnanso"), *Grateloupia*, *Chondrus* and *Ahnfeldtia concinna* ("Saimi") are also employed, but the glue is not of the same standard of excellence. The use of the subsidiary species varies in the different islands and prefectures (Fig. 20): thus *Grateloupia filicina* (Mukade-nori) is used in Shikoku, Kiushui, Kii and Shima, *Chondrus elatus* (Naga-tsunomata) in Kazuoa, Shimosa, Idzu and Hitachi,

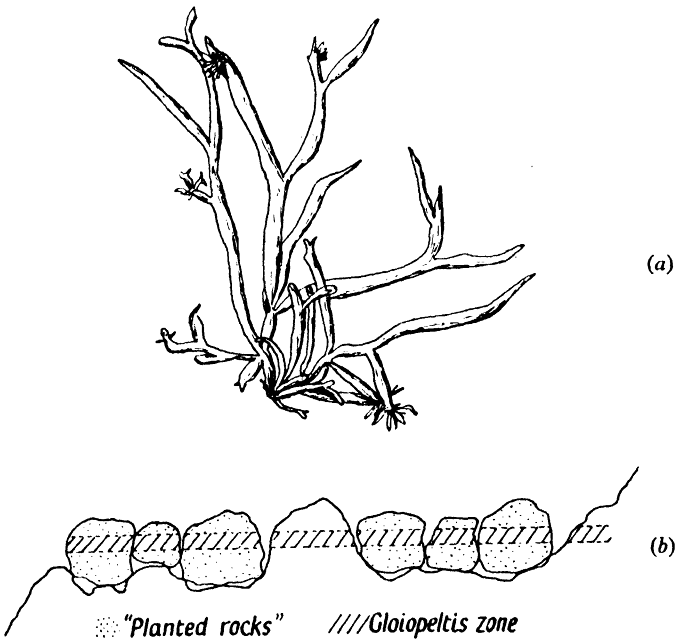


FIG. 42

(*a*) *Gloiopeltis furcata* (× 0.7) (After Okamura). (*b*) *Gloiopeltis* cultivation

whilst in the north of Hondo (the main island of Japan), and in the island of Hokkaido, *Iridaea* is the principal subsidiary alga. Other species of *Grateloupia* ("Tamba-nori") are used in Owari, Mikawa, Shima, Kii and Echizen, and another species of *Chondrus* in Sado, Izumo and Iwami. The use of *Gloiopeltis tenax* (Ma-funori) is largely confined to Hizen and Isushima, whilst in Idzu and Chishima hira-kotiji is frequently employed.

Gloiopeltis grows on rocks in all parts of the Japanese islands, but is most abundant in the warmer waters. There is no particular season for collection, and it is gathered throughout the

year, long-handled hooks or rakes being used for the purpose, though in some places men dive for it. Generally, however, the seaweed is collected during the summer in the north and throughout the winter in the south. In certain places the Japanese even cultivate *Gloiopeltis* by elevating a flat shelf, which normally is not quite high enough above low-water mark, by means of large boulders (Fig. 42*b*). The seaweed then colonises the new boulders. The type of rock is also of some importance and quartzite appears to form the best substrate for funori. After collection the algae are sorted and dried and then sent to the manufacturing centres.

The preparation of Funori used to be carried out in about 100 factories, each employing between fifteen and twenty workers. The industry flourished most in southern Japan with Osaka as the main centre. At the factory the dried seaweed is first cleaned and then soaked in fresh water, or else softened by steaming, after which it is tightly packed in thin layers in large shallow trays or on thin mats: larger species, e.g. *Grateloupia*, *Iridaea*, have to be steamed and chopped. In order to prevent the sheets curling up during the drying process they are sprayed with water at short intervals. As a result of the watering and drying the alga becomes bleached, and when this has gone far enough it is completely dried and several sheets are packed together for market. The sheets as marketed are loose-meshed, thin, flexible and of uniform thickness. A favourite form of package for the wholesale trade used to be a roll three feet high and about six inches in diameter.

Funori is converted into a size by simply dissolving it in hot water. Apart from being used for glazing and stiffening fabrics, it is also employed for stiffening paper and threads, the cementing of walls and tiles and the decorating of porcelain. The name Funorin has been given to the polysaccharide which forms the gluey extract of *Gloiopeltis*, but its exact chemical nature is unknown. Extracts from the subsidiary algae are probably different, though chemically related.

The price of funori naturally varies with the quality. The production is not inconsiderable considering the size of the alga: in 1901 it was just over 1,000 tons, but in 1936 only 714 tons were produced from 4,595 tons of wet weed.

Seaweeds in Medicine. To a small extent seaweeds have long been used by coast dwellers for medicinal purposes, but it is very difficult to prove to what degree their effect can actually be

ascribed to substances in the algae. In the historical chapter (p. 35) mention was made of a number that had figured in the old Chinese *Materia medica*, but in the pre-war German list of medicines only carragheen, agar-agar, *Laminaria* and *Fucus* were given. Although used by the Irish for scrofula and consumption, carragheen (cf. p. 154) only appeared in official medicine at the beginning of the 19th century. Because of its mucus-forming properties, it was used in diseases of the lungs and also to correct the taste of bitter drugs. As may be expected, only the purest carragheen, known as "electum albissimum", is used in medicine. Irish moss has also been employed in irritations of the alimentary canal and in cases of diarrhoea and dysentery. A preparation made from this alga was given to soldiers who had been gassed in the first world war, presumably because it eased the throat. Liver oil emulsions of carragheen have been made (mucin from *Laminaria saccharina* has also been used for the same purpose), whilst one of the more interesting preparations is cotton-wool soaked in a carragheen decoction and dried. This, which is of French manufacture, can be used in place of linseed-meal poultices.

Agar-agar, under the trade name of "Agarol", "Normacol" or "Regulin", is valuable as a lubricant in cases of constipation. If necessary the agar can be made into chocolate-coated pills or a mineral oil emulsion. Agar is also used in the preparation of pills, suppositories, and plasters, and as a base for many ointments. More directly it can be put on underneath bandages in order to assist the healing of wounds, or for covering up a person who has been severely burnt. In dentistry a material known as "Dentocoll" is made from agar and employed for making impressions of gums for manufacturing false plates.

Derivatives of alginic acid also have their uses in medicine. Thus alginates are now replacing tragacanth and the natural gums in the manufacture of greaseless lubricating jellies, whilst according to Lillig (1928) alginoid arsenic, iron alginate and morphia alginate are other substances that can be employed. Iron alginate, for example, is sold in France by pharmacists under the trade name of "Ferrocol". Like agar algin can be used as a binding material in the production of pills and pastilles and for emulsifying the petrolatum base of sulphanilamide ointments. A rather interesting use described by Esdorn (1934) is based upon the fact that alginates are not attacked by the digestive juices of the stomach, so that if it is necessary to give a person some substance that is to have an effect in the intestine, the

material is enclosed in the alginate to enable it to pass through the stomach. Gloess (1919) also recommends the use of alginic acid in the form of an iodine compound in place of cod-liver oil, because it is said to be as efficacious but much less distasteful. During the 1939–45 war algin was used in place of agar for dental moulds: these are not so accurate as the agar moulds but they are more convenient to use. Another dental use is as a covering to dentures made of acrylic resin.

The oarweeds and the wracks are used in various remedies because of the iodine that they contain, e.g. *Fucus* is employed in the form of an infusion in cases of goitre. Another way of giving the iodine is in the form of kelp pills or to use the kelp ash or charcoal, which medicinally is known as "Aethiops vegetabilis". This is recommended by Meier (1935) as a remedy for Basedow's disease. Yarham (1944) says that the brown liquid which can be extracted from bladder wrack is useful in the treatment of sprains, rheumatism and allied complaints. For those who want to slim there are special slimming teas which contain seaweed iodine, usually extracted from one of the wracks. Hoffmann (1935) suggests that the effect of these might be much stronger if *Laminaria* were used because the iodine content is greater. *Laminaria* powder was given by Chaveaux (1927) in France in cases of consumption in order to strengthen the body and help to overcome the disease.

Most of the algae are used in the form of drugs, but there is at least one surgical use. Short pieces of the stems of *Laminaria*, principally *L. cloustoni*, known as "Stipites Laminariae", are employed in surgery for widening fistulae and wound entrances. This use is, of course, based upon their large swelling capacity when moistened. In Germany most of the *Fucus* drugs and *Laminaria* stems were chiefly imported from France or Norway. Germany evidently intended to produce her own material because Esdorn (1934) reports that in 1931 Heligoland provided about 10,000 kg. of *Laminaria* stems and in 1932 slightly more.

The Corsican worm moss, which is the red alga *Alsidium helminthochorton* of the Mediterranean, is regarded as an efficient vermifuge. This seaweed is not very abundant, and in its preparation it became mixed, at first unintentionally and later intentionally, with other seaweeds. Some samples of the drug therefore contain very little *Alsidium* and it may even be absent. It is reported by Garcain (1906) that the drug is only effective so long as *Alsidium* is present, even though in small quantities. It is clear that our knowledge of the efficiency and action of this

drug would be benefited by further study, because the active principle in the alga is a resinous material that apparently has not so far been carefully examined. An extract of the red seaweed *Digenea simplex* from Asia is also on the market under the name of "Helminal" for use in the treatment of worms. Doctors say that this preparation is effective in some cases but not in others. Perrot and Gatin (1912) and Lillig (1928) quote the following additional red seaweeds that have been or are used as vermifuges: *Hypnea musciformis*, especially employed in Greece and Turkey, two species of *Chondria*, dulse (*Rhodymenia*) and a green fresh-water alga known as *Rhizoclonium rivulare*. Yet another vermifuge, which is employed by the Maoris of New Zealand, is made from the bull kelp, *Durvillea*.

A number of seaweeds have also been named by Lillig as useful in cases of lung diseases and scrofula. In Japan *Gelidium cartilagineum** is used for this purpose, whilst in the Mediterranean two other brown seaweeds, *Dictyopteris polypodioides* and *Stilophora rhizoides*, have a similar use. A species of the gulf weed from the Mediterranean, known as *Sargassum linifolium*,† is said to be used in India in cases of bladder disorder, whilst another species, *S. bacciferum*, is reported to be employed in South America as a cure for goitre and kidney diseases. In China *Laminaria bracteata*‡ is used in the form of a viscous solution, known as "Haitai" or "Kwanpu", in menstrual troubles, whilst sugar wrack (*L. saccharina*) is used in India against goitre and in the Himalayas against syphilis.

A recent discovery by Elsner, Broser and Burgel (1937), which may prove to be important from the medical point of view, is that a water-soluble extract can be obtained from carrageen which, even in very great dilution, acts as an anti-coagulating substance for blood. A similar effect can be obtained with a carbohydrate-sulphuric acid ester from the red seaweed *Iridophycus flaccidum* (erroneously called *Iridaea laminarioides* by various writers), known as iridophycin.§ A number of red

* Lillig quotes this as *Fucus cartilagineus*, thus reviving an old name dating back to the 19th century, when classification of the algae was in its infancy.

† Why a Mediterranean species should be employed in India is a matter for speculation. The history of its introduction might perhaps provide a clue.

‡ No reference in standard algological literature can be found for this species: the identification must therefore be regarded as dubious. It is possibly *L. japonica* because it is apparently sometimes prepared like Kombu (cf. p. 175).

§ This is a galactan ethereal sulphate (Hassid, 1933). It is presumed to be of the 1.4 pyranose ring type of constitution with the ethereal sulphate at C_6. The free acid (iridophycinic acid) has been prepared. In solution the substance occurs principally as the sodium salt.

algae have now been tested by Kraul* to see whether they contain similar materials, but of the carragheen group apparently *Chondrus* alone contains it and then only at certain times of the year. The beautiful red seaweed *Delesseria sanguinea* also possesses a strong anti-coagulating action, which is as good as or better than heparin. The effect of this extract can be stopped immediately by the injection of a substance known as thionin. Tests for similar extracts were also made with certain brown and green algae, but only *Chordaria flagelliformis* contained any and then in small quantity.

Among the older remedies is that given by the British naturalist Turner, who has recorded that in the middle of the 18th century dulse was used in Skye as a means of inducing sweating during an attack of fever. The weed was boiled in water and a little butter was added: prepared in this manner it also acted as a purgative. The French algologist Sauvageau tried out its effect and found no cause for dissatisfaction!

In Hawaii the red seaweed *Hypnea nidifica* finds a use as a remedy for stomach troubles, whilst in the same place a cathartic is prepared in the form of an infusion from the small tufted red seaweed called *Centroceras clavulatum*, which is widely distributed in warm waters. A somewhat peculiar remedy, if remedy indeed it is, for headaches is reported from Alaska. Here the Indians of Sitka take the stipe of the bull kelp (*Nereocystis*) and place the thin end in one ear and put the bulb on a hot stone so that steam is generated and passes up the hollow stipe.

Another primitive medicine is recorded in Maori lore. These people, according to Goldie (1904), used to employ *Durvillea* ("rimuroa") as an antidote to scabies: this was a common disease in the race due to their aversion to soap and water, and also because of close contact with their domestic animals. Another brown species† was fermented by the Maoris with the juice of the poisonous Tutu shrub and then used as an aperient.

Cosmetics. This concludes our survey of seaweeds in medicine and we must now describe their use in cosmetics, a subject which should have much popularity with the fair sex. As long ago as the time of the Caesars, Roman ladies used a rouge

* This reference is given by Hoffmann but he gives no indication of the journal in which the work was published.

† According to Goldie the plant was a *Laminaria*, but this is extremely unlikely. The reference gives no real clue to the nature of the alga, but it may have been another *Durvillea* species or *Ecklonia radiata*.

extracted from the *Fucus* wracks, and a similar extract mixed with fish-oil is used to-day by the women of Kamchatka, that far eastern province of Russia, as a means of reddening the faces. The word *Fucus* is in fact derived from the Latin word for rouge.

In recent years Irish moss (*Chondrus*) has become employed as a base in various skin foods, e.g. face paints, pastes, creams and pomades, because a drug company noticed that persons engaged in preparing a carragheen emulsion never suffered from chapped hands. An excellent hand-cleansing lotion, for example, is made by a strong solution of Irish moss in pineapple juice. This concoction is also recommended as a fluid for promoting curling of the hair. *Chondrus* is also added to soaps, and as well as agar is used as a binding material in tooth-pastes. In New Zealand Moore (1944*b*) reports that *Gigartina* spp. is used for similar purposes and in other pharmaceutical preparations. "Manucol", a preparation of sodium alginate, is utilised in various cosmetics and also in sunburn lotions. Algin is, in fact, probably the most useful seaweed product in the industry. It has a wide range of controllable viscosity brought about by the addition of calcium ions, whilst it has the property of producing standard preparations which are transparent, white and almost odourless.

Other Industries and Uses. Apart from cosmetics algae or algal products are employed in small quantities in a number of other industries. In New Zealand brewers have stated that *Gigartina decipiens* is much more efficient than Irish moss as a clarifying agent, but in other industries it is not suitable as a substitute for *Chondrus*. Unfortunately the species contains four parts of arsenic per million and in order to fulfil the Excise regulations it will need to be diluted. A 6 per cent solution of this alga gives a gel comparable to a 4 per cent solution of Irish moss. Moore (1941) gives an analysis of *G. decipiens*, which is of interest for comparison with that of *Chondrus* and allied species (cf. p. 157).

	%
Water	14·3
Protein	11·1
Material soluble in cold water	44·2
Material soluble in hot water	63·0
Ash	15·4

In the textile industry Irish moss, Funori, agar and algin are all valuable sizes and "fixing" agents for mordants whilst

Chondrus has been employed in wall plasters (Haas, 1921). In 1938 a new adhesive was obtained from species of *Chondrus*, *Gigartina* and *Grateloupia*. The alga is first washed in fresh water in order to remove the salt: more water is then added and the mass is subjected to various physical and chemical treatments. The result is a very soluble product which is low in price and has a high adhesive power. *Fucus*, besides providing a rouge for the ladies, has also been utilised as a source of a red dye, whilst alginic acid after treatment with nitric acid is said to yield a brown dye which can be used in alkaline solutions.

One might also mention here the use of the bootlace weed, *Chorda*, on the French coast to make a kind of string. It was possibly used for a similar purpose in the Orkneys and Shetlands, where it is still known as sea cat-gut, or "Lucky Minny's Lines". These names are, at any rate, highly suggestive. On the opposite side of the world the Indians in Alaska take the long stipes of the bull kelp, *Nereocystis*, and after a period of washing, drying and stretching, use them as fishing lines.

In the ceramic or pottery trade there was the important use of soda from kelp in glazing. Although the kelp industry no longer exists, seaweeds are employed for other purposes in ceramics. Thus, funori is used for decorating porcelains in Japan, whilst algin is valuable as a binder and plasticiser. No less than 25,000 lb. of Irish moss are employed annually in the paint industry for the manufacture of what are known as casein paints. In the paint trade alginic acid is also useful as a suspending and emulsifying agent, whilst at the same time it gives "body" to the paint.

Leather manufacturers require a certain amount of Irish moss annually for smoothing leather and giving it a gloss and stiffness. The gelose is melted and brushed on to the leather, which is then polished with glass cylinders. Irish moss is also used extensively in shoe polishes, because the mucilage holds down and smooths out the tiny rough projections on the surface of the shoe leather. Chase (1942) says that one shoe manufacturer in New England used to import until very recently as much as 12,000 lb. of Irish moss annually from Eire.

Paper manufacturers also find a use for seaweed products. The Chinese employ a mixture of agar and lacquer in order to strengthen paper, whilst in western countries agar is used alone as a coating for certain types of paper. At one time there was a plan to make a high-class paper from fibres of the *Yucca* plant, using kelp for binding and filling purposes. Irish moss is also

employed in the process known as the "marbling" of paper. especially for the cut edges of books, because it does not cause the pages to stick together. More recently proposals for using alginate products in the paper industry have been announced, but no further details are as yet available. In an earlier chapter brief mention (p. 30) was made of an unusual natural "paper" made one year from a species of fresh-water algae when the Mississippi overflowed the banks. Another fresh-water alga (*Chaetomorpha* sp.) provides a product known as "pelt" which is used in the West Indies as a packing material.

Dry alginic acid forms a very good substitute for horn and is also satisfactory as an insulating material. Yarham (1944) notes that the studios of Radio City in New York are insulated with specially packed seaweed, though he does not state whether it has undergone any manufacturing process. Some types of alga when washed and dried are employed as a cheap stuffing for furniture, though the marine "grasses" are rather more useful for this purpose.

A substance called *Fucoidin*, which is probably the calcium salt of a carbohydrate ethereal sulphate, is found in the wrack weeds and is very like gum arabic (Kylin, 1913). This material is extremely viscous, even in a 0·05 per cent solution. So far, however, no great effort has been made to extract it in quantity for commercial use. The amount of *Fucoidin* fluctuates during the year, the figures available (Speakman and Chamberlain, 1944) showing a maximum of 9 per cent by weight in the autumn dropping to about 4 per cent in the spring. This material would seem to have possibilities and no doubt will be subjected to further research.

Algal products, mainly from red seaweeds, have been suggested as substitutes for gelatine in the preparation of photographic material, but they have never proved satisfactory, though quite reasonable agar films can be made (cf. p. 121).

Among other and more varied uses there is the Japanese custom of taking the brown seaweeds *Sargassum enerve* (Hondawara, Fig. 43*b*), *Eckloniopsis radicosa* (Antokumé)* and *Eisenia bicyclis* (Arame) for New Year decorations. The main reason for using these species appears to be that they turn green when dried. The stipes of the giant alga *Lessonia* in South America, which may be as thick as a man's thigh, form very useful knife handles because when dry they become as hard as bone. In Southern California the stipes of *Pelagophycus* have a similar

* In the literature on this subject it is usually referred to as *Laminaria radicosa*.

(a)

(b)

FIG. 43

(*a*) *Gymnogongrus flabelliformis* (After Okamura).

(*b*) *Sargassum enerve* (After Okamura) (Both × 5/9)

use in the manufacture of curios but the trade is not considerable.

So far there has been no reference to alcoholic liquors but the literature only mentions one use of seaweeds in this connection. This refers to Kamchatka, where the natives regularly use dulse (*Rhodymenia*) for the production of a somewhat evil-tasting (at any rate to western palates) liquid. The Alaskan Indians also produce an alcoholic drink called "hoochenoo", but, though they do not use a seaweed to make it, they employ the hollow stipes of *Nereocystis* to form a worm condenser in which the distilled liquid is cooled.

The bull kelp of New Zealand, *Durvillea antarctica*, possesses an internal air tissue which is split by the Maoris and then used as a leathery bag in which "mutton birds" can be preserved. The same species, when cleaned out, is used as water bottles by the natives of South America. In New Zealand a marine plant, which was probably a seaweed, called Totaramoana or Rimumoana, was used in olden times before the introduction of iron to make fish hooks. It was bent into shape when green and then became rigid on drying.

Laminarin and Mannite. There are one or two substances, so far not employed on a large scale, which are most conveniently considered at this stage. The first is a polysaccharide sugar, $(C_5H_{10}O_5)n$, laminarin, discovered by Schmiedeberg in 1885, which occurs in the wracks, oarweeds and giant kelps. It has recently been shown (Barry, 1939) that this substance probably consists of a chain of 16 β-gluco-pyranose units with 1 : 3 glucosidic linkages and bent in a spiral form, but in view of the difficulties associated with the structure of algin this work requires confirmation. It has been stated that grape sugar could readily be prepared from this substance on a commercial scale by hydrolysing it with an acid, but so far as is known no attempts have been made to carry out this process. Investigations by Ricard (1931) and Lunde (1937) have shown that the amount of laminarin varies according to the season of the year, e.g. in *Laminaria* it reaches a maximum in the spring months and falls almost to zero in the autumn or winter (Fig. 44*a*). The weed would therefore need to be harvested in the spring for the extraction of this particular substance. Kylin (1915) found that the amount contained in certain brown algae is quite considerable: thus knobbed wrack (*Ascophyllum*) and bladder wrack (*Fucus vesiculosus*) contain up to 7 per cent of their dry weight;

black wrack (*F. serratus*) contains up to 19 per cent; tangle (*Laminaria digitata*) up to 21 per cent; and sugar wrack (*L. saccharina*) up to 34 per cent (see addendum, p. 251).

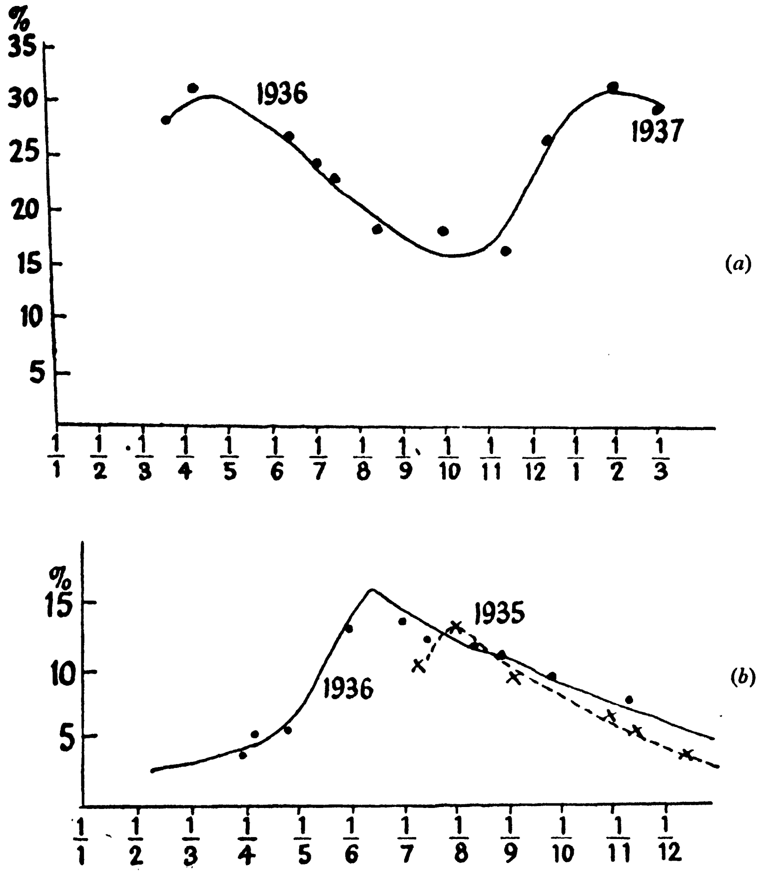


FIG. 44

(*a*) Seasonal variation of laminarin in *Laminaria digitata* (After Lunde)
(*b*) Seasonal variation of mannite in *Laminaria digitata* (After Lunde)

There is also a sugar alcohol known as mannite,* which occurs as a food reserve in several brown algae and is quite abundant

* Hoffmann states that mannite is a 6-carbon sugar. In chemical literature mannite is usually synonymous with mannitol, the alcohol ($C_6H_{14}O_6$), and not with mannose, the sugar ($C_6H_{12}O_6$).

in the oarweeds, though it has only been obtained technically in small quantities (Lunde, 1937 *a, b*). *Laminaria digitata* contains most mannite during the summer (up to 20 per cent) and least in the winter months, when the content falls to 4–6 per cent of the dry weight (Fig. 44*b*). Sugar wrack, as might be expected, contains rather more and may have as much as 25 per cent in the summer. The fluctuation in the amounts of this material and laminarin is almost certainly due to the fact that they are both food reserves, which are accumulated at certain seasons of the year, and are then used up in other seasons. Lunde (1937) considers that mannite has many promising technical possibilities but that at present it is too costly to produce. It could, for example, be used in the preparation of lacquers, whilst plastic products obtained from it are said to be better than those obtained from glycerine. In view of the probable development of the plastic industry after the war this fact may be of considerable importance. Lunde also suggested that mannite could be nitrated to form nitro-mannite, a powerful explosive similar to nitro-glycerine (see addendum, p. 251).

All the algal products we have considered so far in this chapter belong to a group of substances that have aptly been termed Phycocolloids (Tseng, 1945). These polysaccharides have previously been referred to as seaweed gums and seaweed mucilages, but as these are cell-wall constituents they can hardly be classed as gums or exudations. Most gums and mucilages are polyuronides, whereas alginic acid is the only polyuronide from the algae, and it is also unique in being composed exclusively of mannuronic units. The suffix colloid has been added because all these materials can form a colloidal solution when dispersed in water.

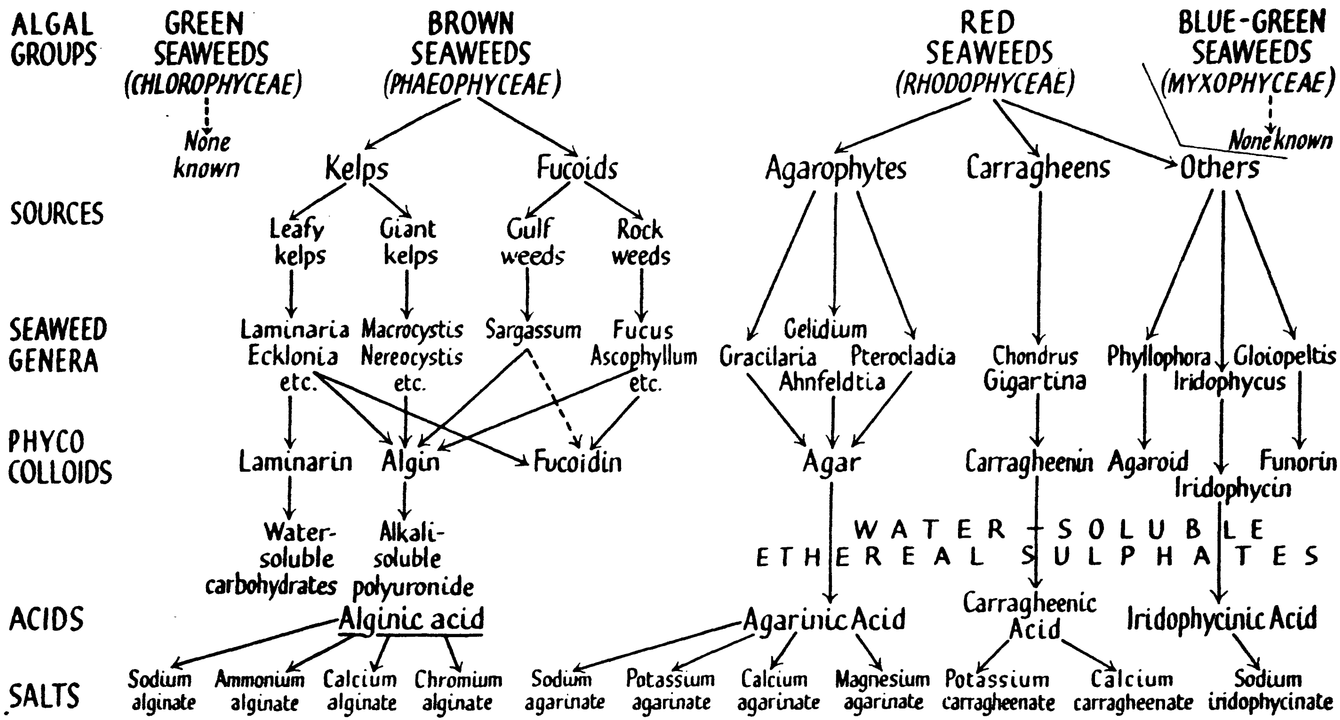
There appear to be three groups of these phycocolloids:

(*a*) The water-soluble ethereal sulphates such as agar (p. 115), carragheenin (p. 155), and fucoidin, with some properties similar to mucilages.

(*b*) Water-soluble reserve carbohydrates such as laminarin and mannite.

(*c*) Alkali-soluble polyuronides as represented by algin.

A tentative arrangement of these phycocolloids showing their sources and interrelations is shown in the accompanying scheme (Tseng, 1945*a*) (p. 222).



Tentative Arrangement of Useful Seaweeds and their Colloids

It has probably become apparent from what has already been said in this chapter that seaweed industries are not always prosperous. As a further example of a somewhat too ambitious undertaking in connection with seaweed products, there was a factory that at one time was established in New England in order to make buttons from dried *Laminaria* stipes. Unfortunately the promoters had not reckoned with the effect of water on *Laminaria* tissues, and the project had to be abandoned as the buttons returned to their original soft condition in the laundry and came off!

In concluding this chapter some reference must be made to the use of diatoms. These are minute brown algae living in fresh or marine waters which have a hard silica coat covered with very fine markings. These striations are so fine that they are used (two species in particular) by lens manufacturers in order to test the definition and angular aperture of microscope lenses. Another use for these algae is associated with fossil species. At some periods in the history of the earth diatoms were so abundant that they accumulated under certain conditions to form deposits which to-day are known as "kieselguhr". Kieselguhr is a fine earthy material composed of the silicified coats of these small organisms. Deposits have been found and are worked in Auvergne (France), Algeria, Bohemia, Virginia and California (U.S.A.) and Australia. The powder is very hard and so it is used for the cleaning and polishing of metals, though the amount involved here is very small compared with its other applications. Its most important use is probably in the preparation of dynamite. The liquid nitro-glycerine from which dynamite is made is by itself very unstable and liable to explode on the least provocation. When, however, it is absorbed by kieselguhr it becomes quite safe to handle and is then known as dynamite. Another extensive industrial use of kieselguhr is also found in the filtration of liquids, especially those of sugar refineries, whilst yet another important application is in the insulation of boilers and blast furnaces. For the latter purpose it is either used in the form of bricks or as a loose jacketing powder. Above a temperature of 1,000°F. it is more efficient even than asbestos because it is more resistant to shrinkage. Considerable quantities of this material are excavated in the U.S.A., the average annual production between 1933 and 1935 being 244,342 tons. An unusual use for kieselguhr is found in eastern Europe and Asia where it is added to the flour because it gives a feeling of full-

ness! On account of this usage some of the races have received the name of earth-eaters.

It will be evident from what has been said in this chapter that seaweeds and their products have a very wide range of usefulness, and though some of the uses are still on only a small scale, they are quite important in our everyday life.

CHAPTER IX

LOOKING FOR SEAWEEDS: THE WORLD'S SUPPLIES

In the preceding chapters evidence has been adduced in order to show that seaweeds play a not inconsiderable part in the economic life of some nations, and that in certain circumstances, e.g. stress of war or famine, their use increases and may extend to countries that normally do not employ them. One would have supposed, therefore, that at some period attempts would have been made to determine with a certain degree of accuracy the amount and distribution of the more important species. It is rather surprising to record that no such attempt was made to survey the available tonnage until the commencement of the present century, presumably because there appeared to be such an abundance of seaweed that it did not seem worth while attempting to estimate the quantities available.

American Supplies. When the dispute between the Kali Syndicate and the American fertiliser manufacturers arose, responsible persons in the U.S.A. realised that some action was necessary, and so a determined attempt was made between 1910 and 1913 to estimate the total amount of weed available in the kelp beds along the Pacific coast, because it was realised that they represented a very large potential supply of potash. Several expeditions were organised for the purpose and the work continued for more than one season. A complete account of these surveys was published by Cameron *et al.* in 1915. The coast was divided into three regions for this survey—Alaska, Puget Sound to Point Conception, and Point Conception to Southern California. Each of these three areas was surveyed by a separate party, and this fact no doubt partly accounts for some of the discrepancies that are to be found when the results are analysed. On the American and Mexican coasts the survey party used a 50-foot 21-ton yacht, whilst in Alaska 30-h.p. motor-boats were used. The boats cruised along the edges of the beds and their positions were established at frequent intervals by means of box sextant and compass bearings. The width of the beds was

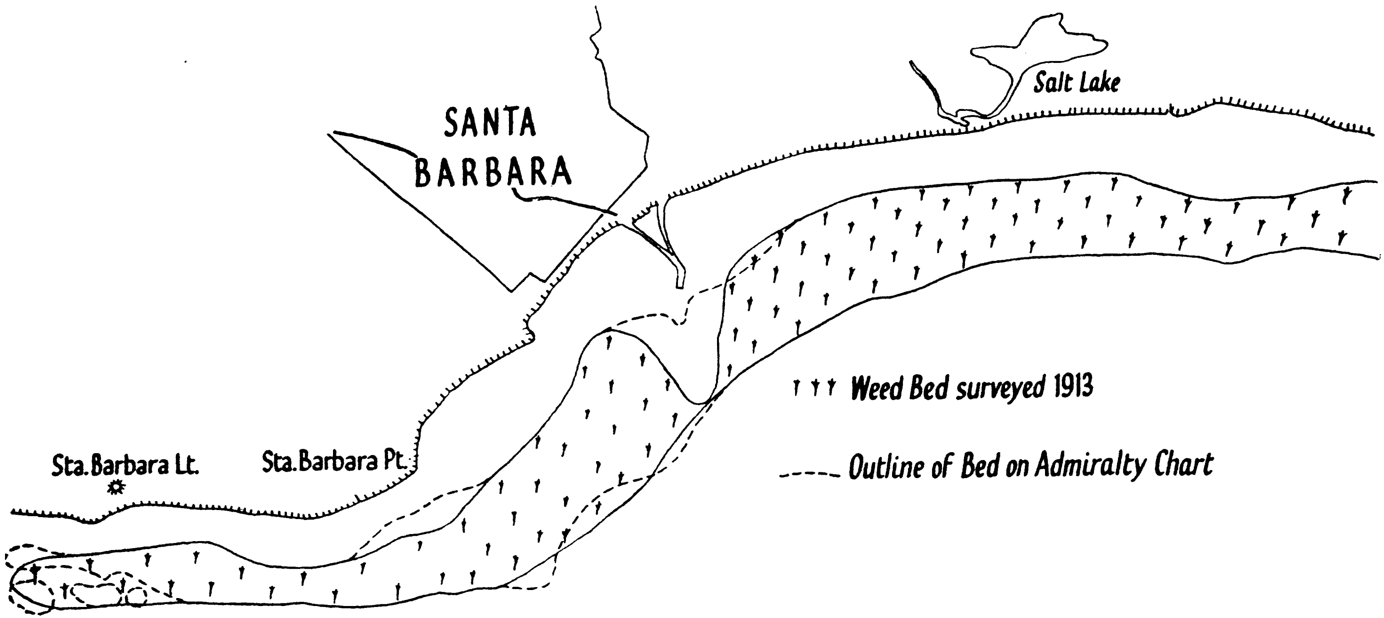


FIG. 45. Map of a portion of an American Pacific Coast kelp bed (From Report 100, U.S. Bur. of Soils)

judged by eye and the surveyors tried to keep their eyes in training by estimating measured distances along the shore. Even with such continual practice it is not at all easy to estimate distances over water, and the accuracy of the recorded widths may be queried. However, surveying the beds of giant kelps could not be unduly difficult because as these big seaweeds all have a flotation apparatus, e.g. ball of *Nereocystis*, bladder of *Macrocystis* and the mid-rib of *Alaria*, portions of them are usually evident on the surface and thus indicate the size and extent of the beds.

As a result of these extensive surveys a beautiful series of maps were prepared and published by the United States Department of Agriculture in 1915, one of which is reproduced in Fig. 45. Although the Pacific coast industry lapsed after 1923 the Hercules Powder Company still retained an interest in the kelp beds, and round about 1930 the company is said to have arranged for the beds to be surveyed from the air by means of aerial photography. The dark patches of seaweed would show up clearly on the photographs, and not only could outlines be mapped with extreme accuracy but also the density of the beds would be evident.

From the legal point of view the beds belong to the states the shores of which they border, and the interested companies lease the beds from the state. No further attempts were made to survey seaweed beds until the commencement of the last war, when the question of utilising algae was automatically revived, especially in England.

New Zealand Survey. At the same time the Government of New Zealand also decided to investigate the quantities of *Macrocystis* available around the shores of the Dominion, with a view to augmenting the supplies of potash. The methods used in this survey, as reported by Rapson, Moore and Elliott (1942), were similar to those used by the Americans in 1911–13. The bulk of the weed is present in the form of beds fringing the shore, and in such cases estimates of width were made every minute as the boat steamed along. The authors considered that the error in length may have been as much as ± 20 per cent, in width ± 15 per cent, and in surface cover ± 25 per cent. There is considerable latitude therefore in the results because these errors would involve a possible maximum increase or decrease in area of nearly 40 per cent. There is no doubt that similar degrees of error are contained in the American figures.

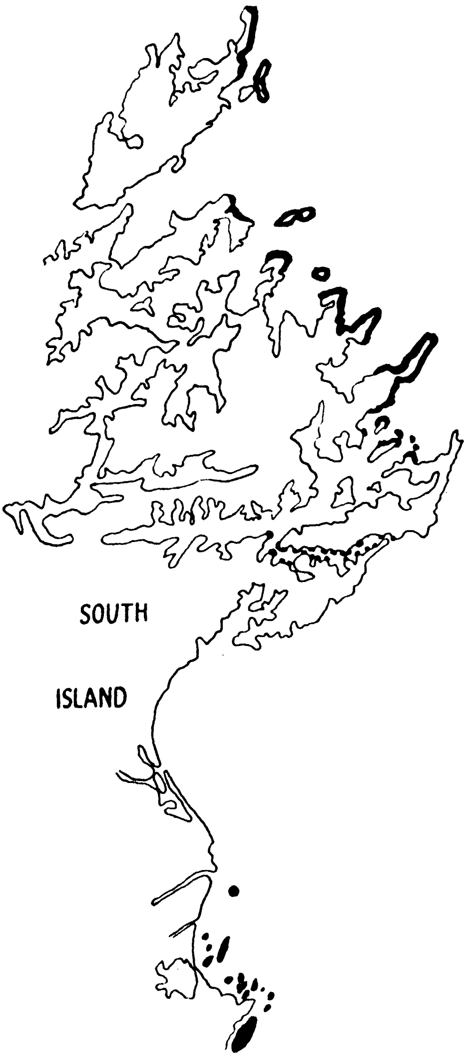


FIG. 46. Map of kelp beds in New Zealand (Cook Strait)
After Rapson, Moore and Elliott)

Figs. 46 and 47 illustrate the distribution of the principal New Zealand beds in Cook and Foveaux Straits, which are the only areas that it is considered would be worth commercial harvesting.*

English Survey. In Great Britain a survey party was organised in 1942 and spent about a year in the field trying to estimate the amount of (*a*) rockweed (e.g. species of *Fucus* and *Ascophyllum*), (*b*) bottom weed (e.g. *Laminaria* spp.), and (*c*) Irish moss† (including *Gigartina*) available in Great Britain (Chapman, 1944). Since this survey offered problems that rendered it more difficult of execution than either the American or New Zealand surveys, novel methods had to be employed as well as the more usual ones. The introduction of these new techniques has probably reduced the degree of error considerably, but it is not possible to estimate the error readily because it varied from bed to bed.

* *Russian Surveys.* In Russia an elementary survey of the far-eastern *Laminaria* beds has been made (Sinova, 1928) and of the *Phyllophora* area in the Black Sea (Sernov, 1910) (Fig. 48).

† The Irish moss survey was soon taken over by other workers (see addendum, p. 249).

FIG. 47. Map of kelp beds in New Zealand (Foveaux Strait) (After Rapson, Moore and Elliot)

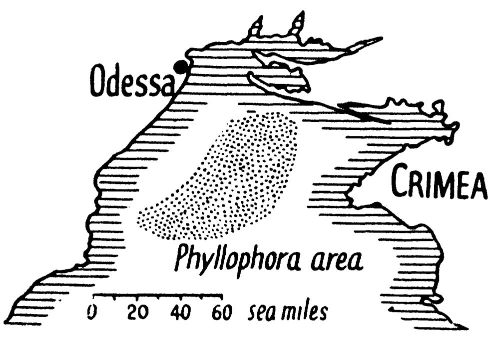
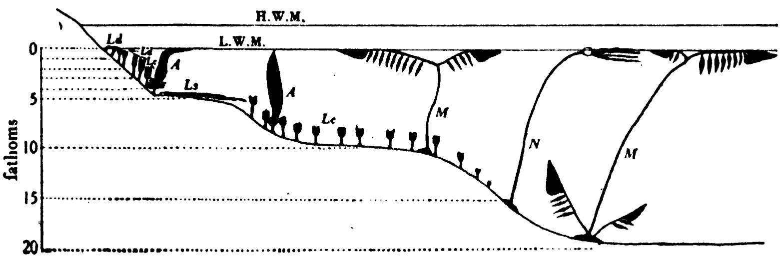


FIG. 48. Distribution of *Phyllophora nervosa* in the Black Sea (After Sernov)

The wracks and the Irish moss were estimated by the simple process of clearing square yards of beach and weighing the cut material. The extent of the beach covered by the weeds could be paced out and the area calculated. As a result, a series of maps was prepared, which, it is hoped, will some day be published. It was found by the surveyors that, after several days of this type of work, it was relatively easy to estimate by eye the actual weight per square yard from the general appearance of the seaweed cover, and being on land it was also easy to estimate by eye the area occupied by the rockweeds, because check measurements could frequently be made. As large-scale maps were used it was also possible to outline the weed areas on the maps and then to calculate the areas directly.



A=*Alaria*, *Lc*=*Laminaria cloustoni*, *Ld*=*L. digitata*, *Ls*=*L. saccharina*, *M*=*Macrocystis*, *N*=*Nereocystis*

FIG. 49

Composite diagram showing relation of British and Pacific kelps to depth of water

When the surveyors turned to the problem of the oarweeds, e.g. tangle (*L. cloustoni*), sea girdles (*L. digitata*) and sugar wrack (*Laminaria saccharina*), the prospect was not so promising. None of these algae reaches the great lengths of the Pacific coast giants; indeed, a plant of 14 feet represents a handsome specimen, and as they grow down to depths of 10–14 fathoms (84 feet), it is evident that even at low tide there will be a considerable depth of water over much of the seaweed bed. This difference in habit is illustrated by an imaginary composite picture (Fig. 49) showing some of the American and British Laminariales growing side by side on the same shore. The surveyors, therefore, had to look for something which very often they could not even see. How this difficulty was surmounted will appear in the sequence, but first the organisation of the survey may briefly be described.

Some information was already available in scientific journals and books, but much of it was inadequate and required confirmation. There were also large areas where no information was available. The survey was therefore divided into two parts, a rapid preliminary inspection which lasted about four months, and a detailed survey during which certain rich areas were selected and surveyed in detail. The length of time occupied in the detailed survey varied, depending upon the length of coastline involved, and generally ranged from a fortnight to four weeks.

The party consisted of four surveyors and in the preliminary survey two worked on boats and two followed by car on land. A number of methods of obtaining useful information were employed during this first phase. Boats were available at certain selected places, and as these steamed along the coast they were stopped at intervals and a grapnel was lowered until it touched the bottom. This was then towed for a short time after which it was hauled in, and if oarweeds were present some portions or even whole plants came up with it. This is of course an accurate method of obtaining information, not only about the existence of a bed but also, by the feel on the tow rope, about its density; however, as time was limited the number of hauls was not very frequent and other sources of information were essential. Furthermore in some places the weather was too bad to permit of any boat work.

The two shore surveyors went from village to village and from town to town, making inquiries about the amount of cast or drift weed which was thrown up annually in each area. It has already been mentioned that the oarweeds produce two kinds of cast weed (cf. p. 58); it is therefore a reasonable assumption that if a place reports large quantities of either type then there should be a big bed in the neighbourhood. Lobster-fishermen also proved invaluable allies. The lobster spends its life among these submarine forests, and the fishermen place the lobster-pots at the edges of the beds or in bare patches within them. If there is a large and flourishing lobster fishery, one may therefore be certain that there are extensive oarweed beds.

Borough surveyors were on occasion extremely helpful. In many of the seaside resorts sufficient cast weed is thrown up to render itself obnoxious to the residents and holiday makers when it decays, because of the dreadful odour. In order to appease everyone the borough surveyor has to remove it, and so by asking these officials, very accurate information could often be

obtained about the cast. Other classes of people were also able to provide information about the cast or even about the seaweed beds themselves. Such persons included coastguards, harbour masters, fishermen and farmers; the last named, however, could only be helpful in those places where seaweed is still collected from the shore for manuring the land.

Another method of surveying which could be used in certain places, was to stand on a cliff fifty feet or more high, and if the sun was behind one's back the seaweed bed showed up darker in comparison with the surrounding bare areas. Unfortunately the relatively small number of nice sunny days set a definite limit to the value of this method. Finally a study of the Admiralty charts indicated those areas where there were extensive shelves of rock at depths of less than 10 fathoms. This last method, however, was not infallible, because although normally oarweeds grow on a rock bottom where the depth of water is suitable, there are apparently places where one would expect to find the algae and they are absent. At present no adequate explanation can be offered for such anomalies. The methods described above only resulted in gross approximations of the available weed supplies. The detailed surveys that followed yielded information that was much more accurate.

During the detailed surveys other and more novel methods had to be introduced. The boat and grapnel technique, however, was a prime essential because it provided infallible proof of the existence of seaweed. The number of hauls made was more numerous and they were conducted in conjunction with the second method that will be described presently. The best type of boat for the grapnel method is a shallow-draught launch with a powerful engine. Some of the oarweeds, especially *Laminaria cloustoni*, are very difficult to detach from the bottom and unless the engine is powerful it cannot be done. Various types of grapnel were used, two of which were specially designed for this work. The ordinary type of grapnel shown in the picture (Fig. 50*a*) was useless, because the slippery fronds of the oar-weeds simply slid over the prongs and it rarely brought up samples. The two-pronged type (Fig. 50*b*) was successful so long as the sea bottom was not uneven. On an irregular bottom one of the prongs would catch in an obstruction and then it often became bent or broken off, and it was therefore essential to have a number of reserve grapnels. As many as three or four of this type could be lost in a single day! The other alternative was to have such a heavy grapnel that the workers soon became

exhausted, because the hauling had to be done by manual labour as most of the boats employed did not have a winch. The third type (Fig. 50*c*) proved very successful because it was designed with an uplifted front end which would encourage it to glide over obstructions. Certain modifications, e.g. a saw cutting blade and an additional V prong, were made to this,

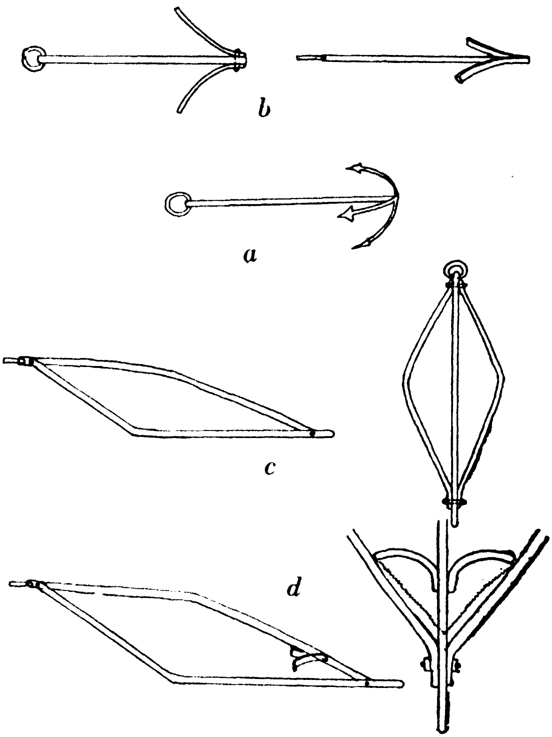


FIG. 50. Different types of grapnel used in surveying beds of *Laminaria* (After Chapman)

and thus evolved the last type (Fig. 50*d*), which was intended to bring up whole plants that could be weighed. Quite a fair picture of *Laminaria* beds could be obtained by this method, especially if used in conjunction with a careful study of large-scale Admiralty charts.

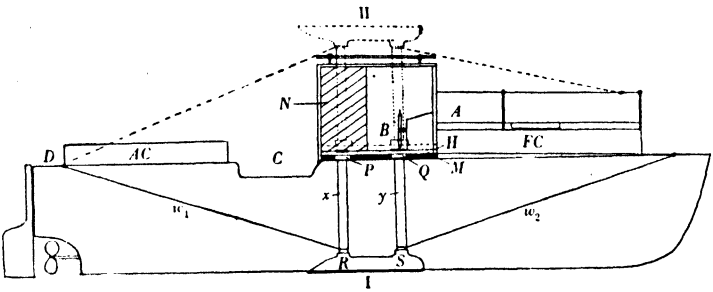
In any area the oarweeds tend to reach their lower limit at a certain definite depth, and once that depth has been established by means of a number of grapnel hauls, it is possible to draw in

the outlines of the bed by joining up the relevant soundings on an Admiralty chart. At every haul the position of the boat was plotted by means of box-sextant readings. In this method an instrument is used to measure the angles between three readily identifiable points on the nearest shore. An apparatus called a station-finder can then be used to reproduce the same angles, and by placing its arms over the three points on the map the position of the boat can be established.

The second method used in the detailed surveys involved the use of an echo-sounder. This is a special machine now installed in nearly all ships, which enables them to take continual soundings so that they will have information about the depth of water in which they are sailing. The basic principle is to send out a sound impulse, which in fact is audible to the human ear, from a transmitter, and this sound wave travels to the sea bed, where it is reflected back up again to the surface. Arrived back at the surface, the echo is picked up by a receiver and amplified, just as a wireless wave is amplified, and made to give a mark on a specially prepared chart. A similar mark is also made on the chart when the wave started out on its journey, so that the distance between the two marks on the record represents not only the time taken for the double journey to the bottom and back, but can be translated directly into terms of the sea depth. Suppose, however, that the sound wave meets an obstacle on the way down, e.g. a whale or some seaweed, before it reaches the bottom, the wave will be reflected back from the obstacle. In the case of seaweed, unless the bed is very dense, the plants do not form a complete obstacle, and so one may get the wave being echoed from the surface of the seaweeds and a second echo from the sea bottom underneath. A somewhat similar effect is produced in the case of a mud or sand layer overlying the rocks. There is a primary echo from the surface of the mud or sand and a secondary echo from the hard rock underneath.

For the purposes of the survey a portable echo-sounder was used which could easily be installed upon any kind of small launch. Some idea of the arrangement that was usually adopted is shown in Fig. 51. The outboard structure carried the transmitter and receiver and could be hauled up out of the water when the boat was travelling at speed. During actual surveying operations a speed of 3–4 knots proved best. The recorder and amplifier were housed under protection in the cabin and were looked after by the senior surveyor. He studied the record as it came out and made the necessary decisions about the course

of the boat and when it was necessary for confirmatory grapnel hauls to be made. Sextant readings were taken by another man stationed on the foredeck whenever the boat changed course or passed on or off a seaweed bed. In some cases as many as a hundred readings were obtained in a single day's work! The man with the grapnel was stationed at the stern and the boat's complement was completed by a skipper and engine man.



A = place of man with sextant, AC = aft-cabin, B = skipper, C = position of senior surveyor, D = position of man with grapnel, FC = fore-cabin, H = hinge, M = out-board plank, N = board with echo sounder, P *and* Q = flanges, R = receiver, S = transmitter, w_1, w_2 = stay-wires, I = working position, II = travelling position.

FIG. 51. Layout of Echo-sounder in boat used for surveying *Laminaria* beds (After Chapman)

The use of the echo-sounder soon showed that beds of tangle (*L. cloustoni*) were reproduced on the records as a series of sharp spikes, each spike possibly representing an individual plant. The "fuzz" of the record also tended to be rather darker when over a bed. Sugar wrack (*L. saccharina*) did not give a convincing record in the areas surveyed and this difference may be correlated with the difference in habit. Tangle grows more or less rigidly upright and has thick tough fronds, whereas sugar wrack has long fronds coming from a relatively thin weak stipe, and where there are currents these will tend to float near the sea bottom as they will be very subject to the influence of the water movement. Sugar wrack usually showed as a light "fuzz" with occasional spikes, but it was not easy to distinguish this type of record from that obtained with a sea bottom of sand or mud overlying rock. Jagged bare rock could give the same kind of appearance as a *Laminaria* bed on the record, except that the spikes were usually much thicker. Big boulders also produced an effect on the record similar to that of tangle, but in such cases the "fuzz" was not deepened. Intense wave action resulted in a "spiky" record,

but this effect could be distinguished fairly readily because the height of the spikes was rather more uniform as compared with the uneven spikes of a *Laminaria* bed. In view of the difficulties and dangers involved the boats were not usually employed in rough weather so that this problem rarely arose. With experience it became quite possible to prepare an outline map of a bed

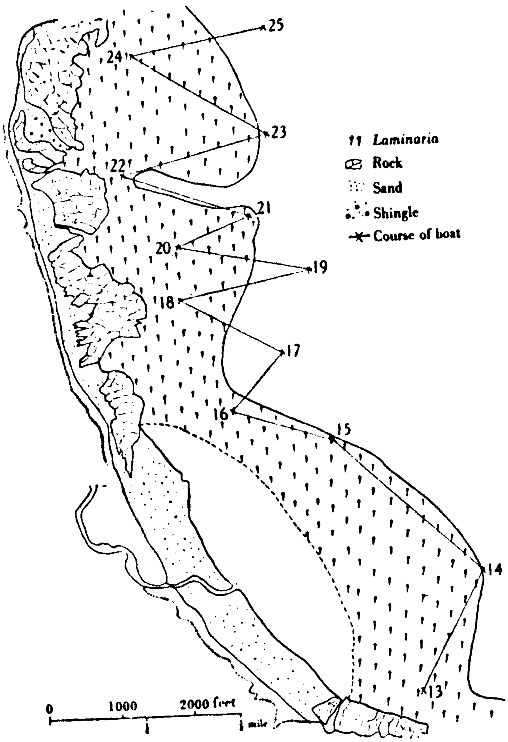


FIG. 52. Map prepared from Echo-sounder record.
(After Chapman)

of tangle using the echo-sounder and grapnel together, but it proved much less satisfactory in the case of beds of sugar wrack. The illustrations (Plates 13, 14) show exactly what the echo-sounding records looked like and how they could be interpreted (Fig. 52).*

Since the original survey further work has been carried out by the Scottish Seaweed Research Association on the above

* These charts tend to fade on keeping and on exposure to light. They must therefore be interpreted as soon as possible after they have been obtained.

methods of surveying. They have found that a better technique is provided by the use of a streamlined view-box together with a calibrated spring grab and modified range-finder for detailed sampling. The use of this equipment confirmed the depths to which measurable weed grows and they have estimated that the sea bed around the Orkney Islands probably contains about 1,200,000 tons (Walker, 1947, 1948; S.S.R.A. Annual Reports, 1946, 1947).

In all the places so far examined it has been found that the density of growth of *Laminaria* species is proportional to the depth in fathoms at which the species grows (S.S.R.A. Annual Report, 1946), though the relationship varies from place to place. It is suggested that the nature of the substratum may affect or control this relationship.

A re-examination of the echo-sounding technique has led to the conclusion that existing equipment is not completely satisfactory, mainly because the sound-reflecting surface of the sublittoral weed is not sufficiently good. This is evidenced by the appearance of only a denser fuzz instead of a clear-cut double reflection (see addendum, p. 250).†

Air Photography. The third method used in the detailed surveys was aerial photography. In spite of adverse reports based on some initial attempts, perseverance brought very striking results, and there is no doubt that, if on any future occasion it should become necessary to survey seaweed beds, aerial photography is not only the quickest but also the most accurate.* In the course of the British survey certain areas were surveyed by all three methods, and the results fitted together beautifully, just like a jig-saw puzzle. The conditions under which the best results from aerial photography can be obtained appeared to be as follows: The most satisfactory altitudes with an F8 camera lens and a yellow filter are between 1,500 and 2,000 feet, but quite good results can be obtained up to 4,000 feet; above that height detail becomes difficult to plot subsequently on to the map. In areas where the weed actually floats on the surface of the sea it is probable that even greater altitudes would prove satisfactory. Bright sunlight is essential and also a cloudless sky, because the shadows of clouds look very like the shadows

* It is now being used by the Scottish Seaweed Research Association (S.S.R.A. Annual Report, 1948) with great success.

† It would seem that in some cases it is possible to obtain records sufficiently clear and distinct from which maps (Fig. 52) can be made, but that in other cases there may be too much fuzz, so that the method is not wholly satisfactory for general purposes.

of seaweed beds and so increase the difficulty of interpretation. When taking the photographs the sun should be more or less behind the camera; if it is too much to either side the water reflects the light and no beds are visible. Experience showed that in northern waters, at any rate, beds down to depths of 5–6 fathoms could be photographed successfully. If the outer limit of the bed lay in deeper water then it had to be obtained either by boat and grapnel or by boat and echo-sounder.

Two types of photographs were obtained. The one is known as a vertical, that is, the area immediately beneath the aeroplane is photographed: the other is an oblique, when an area to one side of the aeroplane is photographed. The vertical photographs are the easiest to handle subsequently for transference to a map. but under certain conditions the oblique photographs are more effective in depicting not only the outlines of the beds but also in showing them to greater depths. The two pictures in Plates 15 and 16 help to illustrate these differences. From the theoretical point of view the vertical should be the most satisfactory type to use unless very big areas are to be covered.

If low-altitude photographs are obtained it is also possible to survey rockweed by this means, especially if a compensating moving film is used, though very useful results can be obtained without this refinement (Plate 17). Under optimum conditions it is possible to distinguish the major types of rockweed from air photographs. It is suggested (Wiggs and Conant, 1945) that surveys of rockweed should be carried out in two stages: a general survey on a scale of $\frac{1}{4500}$ using long-range aircraft fitted with F52 cameras, and detailed surveys of selected areas with slow-flying aircraft fitted with moving-film cameras.

Available Weed Supplies. Now that the methods of surveying seaweed beds have been described, some attempt can be made to assess the quantities of commercially important seaweeds that are available in the world. A complete answer cannot be obtained because information is not always available, and in many cases we only know the amounts collected and much will certainly be left unharvested. There will also be areas where the bottom weeds and rockweeds grow in considerable abundance but where the local inhabitants do not use them: from such places no information will be available.

In Great Britain *Fucus vesiculosus*, *Fucus serratus* and *Ascophyllum* all have a commercial use and the quantities available in certain areas have been surveyed. In order to make the

necessary calculations for the different species the weights were obtained per square yard of vegetation. *Ascophyllum* is normally the heaviest weed, and weights of 30–40 lb. per square yard represent especially heavy beds, but the values usually found over most of the coastline lie between 15 and 20 lb. per square yard. Figures of this order represent high values for the species of *Fucus*, because the more usual weights for these algae range from 8 to 10 lb. per square yard. The total amount of wrack available around the shores of Great Britain is probably of the order of 950,000 tons, though this is a very conservative estimate. Similar attempts, though not so exhaustive, have been made on the Pacific coast of North America to estimate rockweed, and the results for the related species of *Fucus* are very similar. On the shores of North America, however, there is the "feather boa kelp" or *Egregia*, which grows towards low-water mark. Plants of this seaweed may grow up to 30 or 40 feet long so that weights of 70 lb. per square yard are not surprising. The Pacific coast may, therefore, be rather better in its rockweed supplies than Great Britain. Cameron (1915) even considered that there may be a greater tonnage of rockweed along the Pacific coast than of the deep-water kelps, and if correct this would mean something of the order of 20,000,000 tons! So far, however, no detailed survey of the Pacific coast rockweeds has been carried out. The lower potash and iodine contents of these rockweeds, as compared with those of the giant kelps, renders them considerably less attractive as a source of raw material.

During the survey in Great Britain attempts were also made to calculate the amount of oarweed available. At extreme low spring tides representative square yards of *Laminaria digitata* could be cut and weighed. Under very favourable conditions, e.g. in places where there is a strong current, weights of 70–80 lb. per square yard could be obtained, but usually they ranged between 12 and 33 lb. with an average of 15–20 lb. For *L. cloustoni*, which grows in deeper water, no sample squares could be cut, but individual plants brought up by the grapnel and old plants selected from the drift could be weighed. These experiments showed that individual plants weighed from ½ to 2 lb., and as the cutting experiments with *L. digitata* suggested that a distribution of 15–16 plants per square yard was a fair average, beds of *L. cloustoni* were assessed at 16–32 lb. per square yard. Actually when calculating the total tonnage it is desirable to be somewhat conservative in order to allow for thin patches and irregularities in growth, and so the beds were estimated at

26 lb. per square yard when extremely dense, 15 lb. per square yard when dense, 12 lb. per square yard when less dense, 6 lb. per square yard when only moderate, 3 lb. per square yard when thin, and 1 lb. per square yard when very thin. Beds of *L. saccharina*, which is not such a heavy weed, were regarded as having a maximum weight of 6 lb. per square yard. Using these figures as a basis the total amount of readily harvestable oar-weed available around Great Britain was calculated as about 1,500,000 tons, the bulk of it being situated around the shores of Scotland.*

On the Pacific coast of North America an estimate had also been made of the total amount of living kelp present. At the time this estimate was important, because upon it was based the calculation of the amount of potash that could be manufactured *per annum*. The beds of weed varied considerably in density, i.e. the number of plants per square yard, and in composition, e.g. they could consist of a pure stand of a single species or of mixed patches of two or more species. The beds were therefore divided by Cameron (1914, 1915) and his co-workers into the following categories: very heavy, heavy, medium heavy, medium, thin, and very thin; different weights, based on experi-

* Later work (S.S.R.A. Annual Report, 1948) suggests that this figure is much too conservative and a figure of 3,500,000 tons would be nearer the mark.

Weights in lb. per sq. yd.

Type of bed	*Very thin*	*Thin*	*Medium*	*Med. heavy*	*Heavy*	*Very heavy*
Bladder kelp *Macrocystis*	22	23–24	35–44	45– 54	55–64	65+
Bull kelp *Nereocystis* (Calif.)	—	20	—	90	—	165+
Nereocystis (E. Alaska)	55	56–111	112–167	168–224	225–280	281+
Nereocystis (W. Alaska)	45	46–171	172–297	298–423	444–549	550+
Stringy kelp *Alaria* (S.E. Alaska)	2–8	2·9–5·4	5·5–8·2	8·3–10·9	11·0–13·6	13·7+
Alaria (W. Alaska)	63	54	72	90	108	126+

mental cuttings, were assigned to each of the these categories depending on the species present. The table opposite provides an indication of the range in weights that were used for all the different types of bed.

The average weight of a single plant of sea otter's cabbage (*Nereocystis*) is about 18½ lb., and as it has been found that there are about nine plants to the square yard in a dense bed it is evident that the figures in the table for Alaska can only be regarded as exaggerations. Single plants of *Alaria* have been recorded as weighing 6½ lb. or more, but the weight is usually less, and for this reason the figures for weights of *Alaria* in west Alaska must also be viewed with considerable suspicion (Plate 3).

The weights to be used were obtained by cutting sample areas of weed. A similar technique was adopted more recently (Rapson *et al.*, 1942) in New Zealand for *Macrocystis* (Plate 18*b*). Here it was found that the beds were thin as compared with the standards set on the Pacific coast. The average weights per square yard lay between 14 and 22 lb., the highest average being recorded on the north-east shore of Stewart Island (Plate 18*a*). The range of values for an individual square yard was from 3 to 44 lb. In both America and New Zealand the estimates were based on cuttings carried out at three feet below the surface. Rapson *et al.* calculated that harvesting down to a depth of six feet would only increase the yield by 15–20 per cent.

In New Zealand the results of the survey, which appears to have been carried out with rather more care than that on the American Pacific coast, indicated a total potential harvest of 78,000 tons in Cook and Foveaux Straits, which were the only areas surveyed.

Macrocystis has been regarded by Cameron (1912) and Rapson *et al.* (1942) as an extremely valuable plant, because it was anticipated that two crops could be harvested each year from pure beds, and the calculations of yield were based upon this assumption. Rapson assumed that in New Zealand two cuttings a year would be practicable, and that they would yield one and a half times the quantity present at the time of survey. Experiments in New Zealand showed that only plants cut in October had regained their original length by the following August, so that two harvests would only be economically advisable if one of the crops was gathered in October.

This, however, is not the whole story, because a steady rate of regrowth is assumed. The rate of growth of *Macrocystis*

depends largely upon temperature, and the effect of this factor upon the yields in North America was very pronounced during the first world war. When this temperature effect was investigated it was observed that the greatest yields were obtained in waters of low average temperature. Another factor that has to be faced in the utilisation of *Macrocystis* is that a bed decimated by a storm would not be ready to harvest again for at least two years. In the case of *Macrocystis* the reproductive bodies or spores are produced more or less throughout the year, but Brandt (1923) found that those that germinate in the early winter subsequently show the most rapid growth. If the bed is damaged by a storm in the early winter relatively few spores will be disseminated, whilst those that are produced later in the winter and spring will germinate but the sporelings do not grow very much until the following autumn and winter. As a result it may be two seasons before a bed is replaced.

Under certain conditions *Macrocystis* is also subject to a bacterial disease known as "black rot", and if this once starts in a bed the whole area is soon decimated and several years will elapse before the bed is once more fit to cut. At present our information about this disease and the conditions under which it develops is decidedly meagre. It is known, however, that it causes most damage at sea temperatures between 18° and 20°C., and that the organism responsible for it makes very little growth below 15°C. It is therefore promoted by warm weather, although the range of temperature is somewhat narrow. This partly accounts for the fact that it is not more serious than it is. The bacterial organism responsible for the disease will only live in the presence of oxygen, and so plants that are always submerged are not susceptible to attack because sea water does not contain sufficient dissolved oxygen to enable the organism to thrive. It can therefore only attack plants whose fronds are floating on the surface. Harvesting is extremely beneficial in that it helps to control the disease, and as soon as signs of black rot appear in a bed it should be mown. Cutting beds during May and June may assist considerably in stopping attacks of black rot. Kelp attacked by the disease is not satisfactory for commercial purposes; the plants are watery and only yield half the amount of potash they should, and the Hercules Powder Company also found that they would not ferment properly in the acetone process (p. 87). The extent to which the disease damages a bed may be illustrated by the record of a bed that normally yielded 3,000 tons, and which only gave 300 tons after it had been

attacked. If the industry ever becomes important it is clear that some means will have to be found for controlling or eliminating this disease. Workers in New Zealand have not so far reported that this disease occurs in that region.

The Pacific coast survey resulted in the mapping of about 390 square miles of kelp beds between Alaska and Lower California, with a total estimated annual harvest of 59,305,500 tons!

In making the calculations of the potential harvest the figures for weights of weed given in the table on page 240 were used, and it was also assumed that *Macrocystis* beds could be cut twice in a year, and that equal weights of weed would be obtained for each cut.* This figure, however, is certainly an overestimate because the weights for weed beds in Alaska need drastic reduction. It is probable that a more accurate estimate based on reduced weights and only partial recutting of beds of *Macrocystis* would give a potential yield of about 26,400,000 tons, but even so this is very striking when compared with the relatively small amount of kelp available in Great Britain. The adjacent coasts of British Columbia have never been properly surveyed, and although it has been estimated that there are 13,000,000 tons of weed on those shores, for reasons similar to those given above it would be desirable to regard 6,000,000 tons as a more realistic value.

In Chapter IV it was stated that in the last thirty months of the 1914–18 war 620,000 tons of kelp were collected by the Hercules Powder Company, and it is evident that this represented only a small fraction of the total amount annually available on the Pacific coast of North America. In fact, between 1915 and 1919 the harvest, according to the published figures, was in most cases only 3–5 per cent of the total possible. The post-war analyses by Brandt (1923) of the cutting returns show that only two beds were at any time completely harvested. One of the reasons for this poor result was a failure to cut the beds methodically, the good patches being picked out first, so that towards the end only poor patches were left and much steaming time was wasted: another contributory cause was the mechanical inefficiency of the harvesters, because it is possible that as much as 50 per cent of the weed cut was lost before it reached the conveyor belt. The following table gives some indication of what was achieved during these years.

* Cf. p. 241, where in New Zealand only half as much was estimated for the second cut.

Year	*No. of beds cut out of total of 42*	*% yield from the beds actually cut*
1916	6	24·0
1917	31	8·4
1918	39	6·7
1919	12	1·8
1920	10	4·0

It is clear therefore that harvesting kelps or oarweeds is not a process that at present can be regarded as 100 per cent efficient. Rapson (1942) and his co-workers in New Zealand concluded that an 80 per cent harvest is possible, but they only allowed for the inaccessibility of portions of the beds and not for any mechanical inefficiency. It is probable therefore that even their figures err on the side of optimism. For the areas surveyed they estimated a total annual harvest of *dry Macrocystis* amounting to 9,300 tons, obtained from one and a half times the total amount of wet weed (114,000 tons*), of which 80 per cent is harvestable. In the light of criticisms made above, it is probable that an estimate of 6,000 tons of dry *Macrocystis* would be more accurate. On the other hand the harvesting of rockweed (the wracks) should approach very closely to complete efficiency, and therefore in this respect it is at least superior to bottom weed as a crop. The chief disadvantage lies in the fact that rockweed has to be harvested by manual labour, whereas mechanical means can be employed for the oarweeds.

The size and extent of some of the Pacific beds are so considerable that it is perhaps worth while trying to visualise them. In south-east Alaska there are seven beds each alone containing over 1,000 acres of weed, the largest being 3,634 acres. In west Alaska there are five beds of similar magnitude, three of them occurring near Low Cape on Kodiak Island: these three beds combined occupy a total of 4,027 acres. There is a big grove off Santa Barbara in California which occupies nearly four square nautical miles, another one off Los Angeles with an area of 2·4 square nautical miles, whilst the largest lies off San Diego with an area of 7·7 square miles, and an estimated yield of over 1¼ million tons. This perhaps explains why most of the American kelp companies located their factories in or near San Diego. The largest bed in New Zealand lies south of Cape Campbell, and is about four miles long by one mile wide, and was estimated to consist of 2,690 acres. Generally, however, the New Zealand

* They assumed that more than one cutting is practicable.

beds are much smaller than those on the Pacific coast of North America. This difference is probably related to the configuration of the land and the geology of the sea bottom.

It has been seen that Japan is another big utiliser of seaweeds, and some idea of the amount growing around her shores can be obtained from the trade statistics of the various articles manufactured. The information for the year 1936, which appears to be the latest available, is summarised in the following table.

	Tons collected
Iwo-amanori collected wild ..	2,240
Amanori (*Porphyra*), cultivated	31,539
Kombu (*Laminaria*)	293,284 (475,316 tons in 1934)
Wakame (*Undaria*)	44,601
Funori (*Gloiopeltis*)	4,595
Kanten (*Gelidium*)	12,000

When the small size of some of these seaweeds is considered the total harvest represents no mean feat, especially in the case of Amanori. Apart from the *Laminaria* used for kombu, a considerable quantity is also harvested for the production of iodine. It is known that 115 tons of iodine were manufactured from oarweeds in 1929, and this must have involved the collection of at least 1¼ million tons of wet weed; it has indeed been suggested that it required more than two million tons, but this figure would seem to be an overestimate in the light of available information (cf. p. 175). This means that the Japanese, without any mechanical cutters, must harvest, for kombu and iodine manufacture, in a single year at least one and a half to two million tons of *Laminaria* alone, almost as much as the entire crop around Scotland! In adjacent far-eastern waters of Siberia, the Russians (Sinova, 1928) have estimated that they could secure an annual harvest of about 72,000 tons, mainly of *L. japonica*. Between 1925 and 1929 an annual harvest of about 2,500 tons was regularly collected (Pentegov, 1929).

In other areas it has been calculated that there is enough *Gracilaria* in New South Wales to supply 100 tons of agar annually, and on a fresh weight basis this would require a potential harvest of at least 1,000 tons of wet weed per annum. In England *Gigartina* can be used for the same purpose, but the potential harvest is relatively small and would not yield more than 350 tons of wet weed. The Germans have considered the possibility of using oarweeds, but as much of their coastline is sandy it is not suited to the growth of these species. They have

estimated, however, that Heligoland should be able to supply about 1,000 tons of dried oarweed, which means, for that tiny island, a potential harvest of about 4,000–5,000 tons of wet weed.

In an article Delf (1944) has pointed out that there are two views concerning seaweed supplies for commercial purposes. On the one hand there are those who believe that the supplies are inexhaustible, whilst on the other hand there are those who believe that the seaweed vegetation is "like the land crops, subject to fluctuation unless proper precautions are taken". In 1884 the chemist Stanford, addressing the Royal Society of Arts, claimed that supplies were almost unlimited, whilst in more recent times a pamphlet about "Manucol" states that "certain marine plants form an inexhaustible source of raw material". It may be remembered, however, that in Brittany and Japan harvesting was, or still is, subject to regulations, and this rather suggests the opposite view. There is also the fact that beds of the giant kelp *Macrocystis* may be eliminated by the black rot disease or unsuitable temperatures, and then harvesting must cease in order to allow for effective recovery just as in land agriculture. Rockweed and beds of oarweeds and kelps that grow in the vicinity of the towns may be adversely influenced by the outflow of sewage, and in certain areas there is no doubt that oil is having a very serious effect upon the condition of the plants. At present, however, we do not know very much about the deleterious effects of sewage on these marine plants, and this is a subject that requires further study.

The result of any complete harvesting of kelp beds will probably not prove to be so disastrous in relation to subsequent crops as one might imagine. The oarweeds and kelps reproduce by means of minute spores which are capable of swimming about in the water. After a time they settle down and grow into a tiny microscopic filament which bears the sex organs, some plants being male and others female. So long as some adult sporing plants are left during harvesting it is probable that supplies will not be greatly decreased because the number of spores produced by a single plant run into astronomical figures. The fact that harvesting is not 100 per cent efficient would in any event ensure that a sufficient number of plants would be left. It has been calculated that a single square millimetre of *Laminaria digitata* frond produces about 84,000 spores. More recently Kirigeva and Schapora (1939) estimated that a single plant of sugar wrack (*L. saccharina*) produces 11,890,800,000 spores, whilst a single plant of tangle (*L. digitata*) produces 26,719,000,000! With this

output of reproductive bodies one is only surprised that the plants are not even more abundant. It can only be concluded that the mortality rate of spores and sporelings must be very high. Work carried out, and still proceeding, upon the reproduction of British oarweeds has shown that their times of reproduction vary. Thus, *L. saccharina* fruits in summer and *L. cloustoni* in winter, whilst *L. digitata* spores between April and November, with maxima in spring and autumn. Points such as these may be of considerable importance in the planning of harvesting operations (see addendum, p. 250).

It has taken the last major war to make us realise that our information about the regeneration of these seaweeds from cut stumps left after harvesting is extremely meagre. There are vague ideas about the number of seasons that must elapse before the weed can be cut once more, but no accurate information is at present available. It would seem, for example, that *Fucus vesiculosus* requires at least two years to recover, whereas knobbed wrack (*Ascophyllum*) probably needs four years. In the Orkneys, where *Ascophyllum* was commonly used, the old kelp workers usually reckoned that three years must elapse between harvests from the same site. If it requires several seasons for a cut rockweed bed to recover, then it seems evident that if operations on a large scale were initiated some regulations might be necessary unless there was a sound cutting policy. Should the time come when seaweeds are utilised in western countries on a large scale, then it is obvious that we shall want to know more about the factors or conditions that control the rate of growth, in order to determine whether the time taken to regenerate may not be accelerated. Investigations for this purpose have been carried out for many farm crops, and there is no reason why they should not be initiated for marine crops, though it will probably be more difficult.

In the case of the rockweeds it seems that the effect of cutting an area requires to be studied more closely in relation to the types of seaweed that recolonise the area. For example, after denuding a strip of beach, David (1943) found that at Aberystwyth *Ascophyllum* appears to return to the upper part of its original zone and may even invade the zone of the next higher belt, normally occupied by *Fucus spiralis*, whereas the main zone formerly occupied by the *Ascophyllum* tends to be recolonised by *Fucus vesiculosus* (bladder wrack). It also appears to be essential that green seaweeds should re-occupy a cleared area first, because they presumably provide a suitable substrate on

which the germlings of the wracks can settle. If one could produce a similar artificial substrate it should be possible to hasten the time of recolonisation after harvesting and also perhaps to increase the area available. The effect of cutting upon rockweeds varies with the species. In the case of *Ascophyllum* new shoots arise from the basal holdfast, but in the case of *Fucus* the cut ends commonly regenerate and give rise to new branches. With either species, cutting enables light to have access to the rock underneath and germlings of new plants soon find a foothold.

Experiments carried out since 1946 by the Scottish Seaweed Research Association (S.S.R.A. Annual Report, 1948) on regrowth of *Ascophyllum* have shown that it is unwise to strip an area completely as it leaves no fruiting plants to provide spores for recolonisation. If not less than 11 inches of thallus is left by the cutters the original cover is regained in two years, so that biennial harvests would be possible.

In concluding this account of the economic aspects of the seaweeds one is impressed by the multiplicity of uses for their products, but at the same time there is no doubt that as a raw material they have not yet been as fully exploited as they might. Thus, further research on the biochemical and technical aspects may lead to increased demands for seaweeds. This would seem to be especially true of the algin compounds. The failure to exploit them fully is to some extent due to the fact that, apart from the giant kelps, no efficient and cheap method of harvesting has yet been devised. Another contributory cause would seem to be a failure to devise a technical process in which the by-products are produced sufficiently cheaply to enable them to compete with similar materials from other sources.

The supplies of raw material are undoubtedly vast, and they can never be exhausted as they are replenished by the operations of nature. The day, however, has yet to dawn when they will form the basis of a successful and flourishing industry in western countries.

ADDENDUM

SINCE this volume went to press some new and relevant information has been published, especially in respect of seaweed resources.

In England, Newton (1948, 1949) has reported that *Gigartina stellata* and its variety *acuta* have been in recent years the chief source of agar (see p. 109). Studies on the biology of this plant have shown that it is an annual or pseudo-perennial and that regeneration can take place from the haptera, so that if these are left a further crop is assured. Newton also demonstrated that harvesting should take place when the plants are attaining their reproductive peak, because at that stage the gel strength of the extract reaches a maximum value. Plants cast up in the drift should be neglected because some of the gelling qualities of the gelose have been lost.

Newton (1949) in collaboration with other workers gives an account of the present agar industry in Great Britain and of the experimental work associated with it. Since 95 per cent of the weed harvested is *Gigartina stellata* most attention has been paid to that species. Detailed studies of the various forms and of the life cycle have been in progress, and as a result of these it is recommended that there should be only one harvest per cnnum, and that the material must be hand-picked so as not to destroy the holdfast. Harvesting of *Chondrus*, which was also investigated, demands greater care because the whole plant is more readily torn from the substrate.

Extensive chemical investigations have shown that both species yield about half their dry weight in a substance, which forms a highly viscous gel. The viscosity of this gel can be controlled by the addition of electrolytes, of which potassium chloride proved the most suitable. In this respect the results are similar to those found in Carolina (see p. 108). The best product was produced by heating the extract with caustic potash, which should not exceed 15 per cent of the dry weight of the extract, and then neutralising with hydrochloric acid. The severity of this treatment is also important, and the best product is obtained when it is carried out in an autoclave for eight hours at 20 lb., or for two hours at 40 lb./sq. in.

Any of these treatments yield an agar which has a deep yellow colour, but it can be decolorised by treating with activated charcoal. Agar prepared in this manner and from these algae differs from Japanese agar in that the gel is much more transparent. It also has a lower melting point and dissolves more readily.

Lami (1949) has reported that *Eucheuma gelatinosa* and *Gloiopeltis coliformis* are now used for agar production in Indo-China. The product is replacing algin as a creaming agent in the manufacture of natural rubber. The use of these two species is very interesting because they do not appear to be used for this purpose elsewhere in Indonesia (see p. 90).

Newton (1949) states that there was a small agar industry in China with an annual production of about 75,000 lb., but during the war a new process of manufacture was tried out. The principal advantage of this method was elimination of the freezing process, so that the agar could actually be made by the shore where the weed was collected. The resulting agar is also said to have a higher gel content.

Since 1945 the Scottish Seaweed Research Association (Walker, 1947 *a*, *b*, 1948) has been busy rechecking with more care on the rapid survey that had perforce to be carried out under war conditions (see p. 228). They abandoned air photography and echo-sounder, and the employed a view-box in conjunction with a calibrated grab. Statistical studies have shown that, assuming the weed to be evenly distributed, estimates of quantity are likely to have an error of $\pm$ 40 per cent. This is comparable with a somewhat similar figure that had been arrived at independently by the present author in the original survey. Further data have been provided that show how the density falls off with depth. Thus the cover generally around Scotland is about 87 per cent at one fathom, 60 per cent from four to six fathoms, 25 per cent from seven to eight fathoms, and nil at nine fathoms.

One interesting outcome of this study has been the establishment of a relationship between depth and weed density. This must be worked out for each area, and where the tides are strong cover must also be included.

Work carried out on behalf of the S.S.R.A. by Parke (1948) has shown that in the case of *Laminaria saccharina* complete regeneration of the frond after cutting only occurs if the plant is less than one year old. At one period in the year growth is slow and at another period it is rapid: the maximum weight is

reached in the second season at the end of the second period of rapid growth. Apart from this seasonal variation in weight there is a variation dependent upon region, i.e. open sea or enclosed loch, habitat and depth.

In view of the possible importance of cast the S.S.R.A. have studied this source in certain parts of Scotland (Annual Report, 1947). The maximum quantity usually occurs on the first day of a big cast and unless it is soon removed bacterial decay sets in. There do not appear to be any specific conditions which would aid the forecasting of the location or quantity of a cast. This is unfortunate because very considerable quantities may be thrown up. Thus in North Uist 37,400 tons were cast up in 1947, 11,500 tons in Tiree and 13,000 tons on the Island of Sanday in the Orkneys.

The uncertainty of the castweed renders it essential to devise methods of harvesting the growing weed. A cut-and-suck method was at one time expected to provide a convenient means of securing the weed (Hay, 1947). This method has disadvantages and more recently (Annual Report, 1948) other methods have been explored. These trials have demonstrated that the grapnel principle is the most promising, the weight of weed harvested being proportional to the size of the grapnel. At present efforts are being made to design an arrangement which will enable the principle to be adapted to a continuous system.

Chemical analyses have shown that there is apparently little variation with age in the stipes of *L. cloustoni*: there is, however, considerable variation with depth at which the plant occurs and with season. Seasonal changes are usually reproducible from year to year but not always. In one particular case it is believed that late frosts and bright sunshine affected the mannitol and ash content of *Laminaria digitata* and *L. saccharina*. Such changes appear to be relatively minor and commercially the weed can generally be harvested at the season of maximum mannitol or algin content.

The seasonal variations, described above, that occur in the sublittoral weeds are primarily due to variations in the frond, where photosynthesis occurs, and not to changes in the stipe. The seasonal fluctuations are by no means the same in the different species. In *L. cloustoni* the maxima occur in May (S.S.R.A. Annual Report, 1947), in *L. digitata* and *L. saccharina* from the open sea in February, and in the last-named species from lochs in January. These are all matters that would need consideration in making harvesting plans.

Rockweed supplies have also been studied and nearly 181,000 tons have been estimated to occur over 540 miles of coast.

	Total tonnage	Density tons/acre
Outer Hebrides	125,136 tons	36
Inner Hebrides	8,263 ,,	30
Orkneys	38,774 ,,	21
N. and N.W. Scotland ..	8,540 ,,	24
Total	180,713 ,,	

It has been found that there is, as one might expect, a monthly variation in the fresh weights of rockweed due to growth and decay. These variations do not appear to be reflected in the average monthly dry weights so that commercially the season of the year is not important in respect of harvesting.

The Scottish Seaweed Research Association have also been carrying out experiments with seaweed as foodstuffs for animals. The starch equivalent of *Laminaria saccharina* collected in October is higher than that of hay but lower than that of wheat. Although these seaweeds cannot be regarded as a good source of protein, much of the laminarin is digested together with a considerable quantity of the other carbohydrates. Their main value as animal food would therefore appear to lie in the high carbohydrate content.

Composition: % dry weight basis

Species	*Nitrogen (Protein = N × 6·25)*	*Fat*	*Ash*	*Phosphorus*
Alaria esculenta	2·13		29·2	0·43
Ascophyllum	1·76	2·47	19·8	0·16
Fucus evanescens	2·70	1·80	17·7	0·25
Fucus serratus	0·59		4·5	0·13
Fucus vesiculosus	1·73	0·43	21·5	0·18
Laminaria agardhiana ...	2·09	1·96	27·2	0·22
Laminaria digitata ...	1·69		27·9	0·23
Laminaria longicruris ...	1·84		34·8	0·16
Enteromorpha intestinalis...	2·58		45·4	0·31
Ulva lactuca	3·75		29·1	0·29
Chondrus crispus	1·94		26·8	0·11
Rhodymenia palmata ...	4·04	3·78	26·7	0·32

Interest in the seaweeds as animal foods and manures is evidenced in Canada, where analyses of certain algae have been carried out (Macpherson and Young, 1949). These may be compared with those reported by earlier workers (see pp. 129, 143).

In New Zealand, Little (1948) has studied the rate of decomposition of certain large brown seaweeds when dug into the soil. *Macrocystis*, *Ecklonia* and *Durvillea* decompose completely within four months, but *Carpophyllum* is still recognisable after one year. The bulk of the sodium, potassium and chlorine is released in the first fourteen days, so that these elements are made available very rapidly. It is likely therefore that the minor elements will be made available equally rapidly.

Crop experiments, using the same algae with dwarf beans as the crop, showed that *Macrocystis* and inorganic fertiliser both increased the yield. The use of the seaweeds appeared to have no effect upon the disease resistance of the dwarf bean to halo blight. This does not mean, of course, that the algae might affect the disease resistance of other plants to other diseases.

Finally Rose (1949) has re-emphasised in rather different words much of what is contained in the preface of this volume and much of what is implicit in the text. He points out that there are three primary requisites for a successful seaweed industry. First there must be an adequate supply of the raw material, and this factor involves a study of the growth habits of the species involved, surveys of the actual beds, a study of methods of collection, and investigation of means of storage.

Secondly one requires a cheap and efficient extraction process, and thirdly a market has to be created for the products and continuously enlarged.

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PLATES

* *By courtesy of U.S. Dept. of Agriculture* (*Report* 100).
† *By courtesy of the Irish Tourist Association.*

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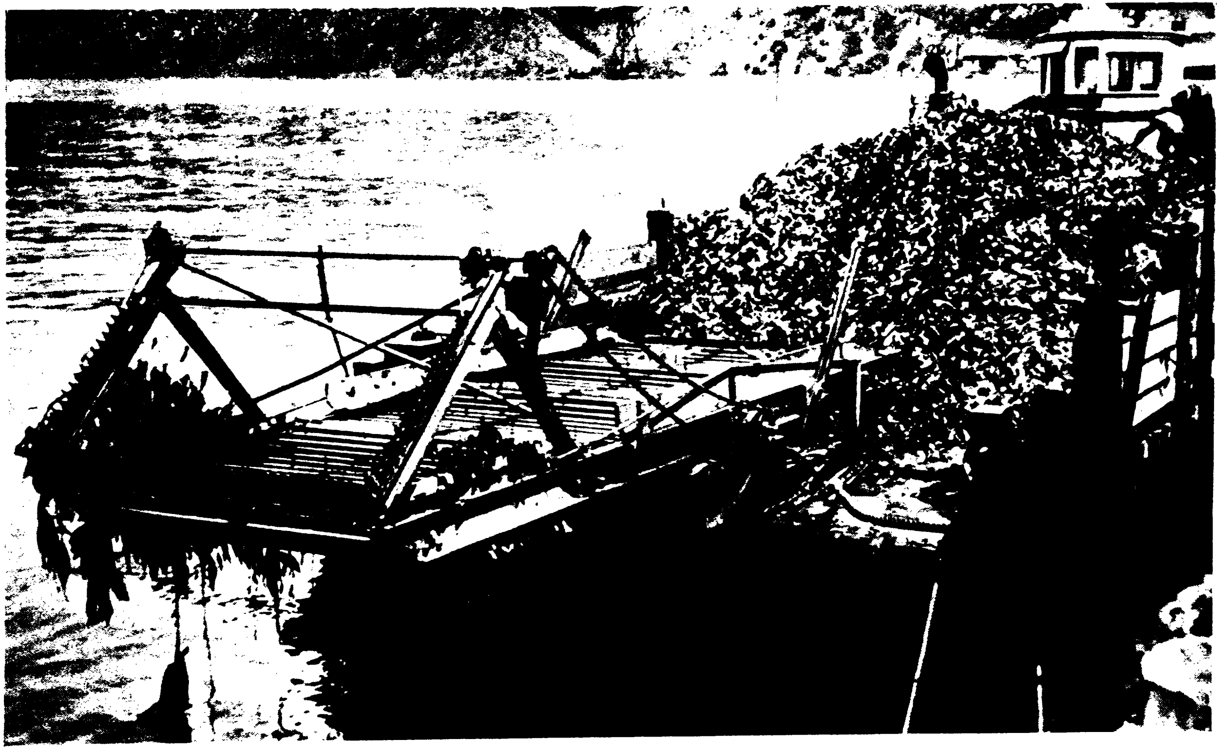


Kelp harvester of the Lorned Manufacturing Company

Collecting kelp by hand

Taking kelp off the shore

Fucus farms, Achil Sound, Ireland
(*After Cotton*)

Store of baled *Pterocladia* ready for processing into Agar (New Zealand)
(*After Moore*)

Collecting kelp by boat. This is the old slow method of collection, very similar to that still used by the Japanese

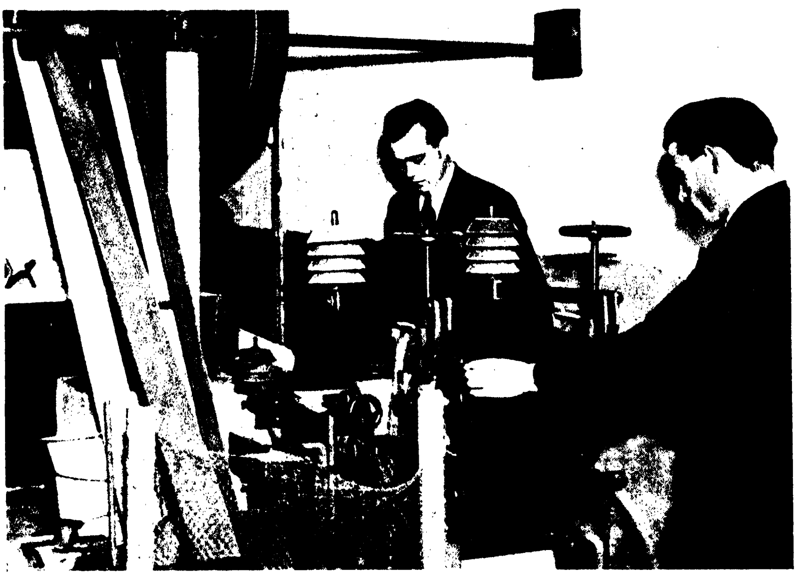
Inspecting kelp drying on a specially built stone wall in Western Ireland. This is an uncertain process as it is subject to the vagaries of the weather

Kelp ricks

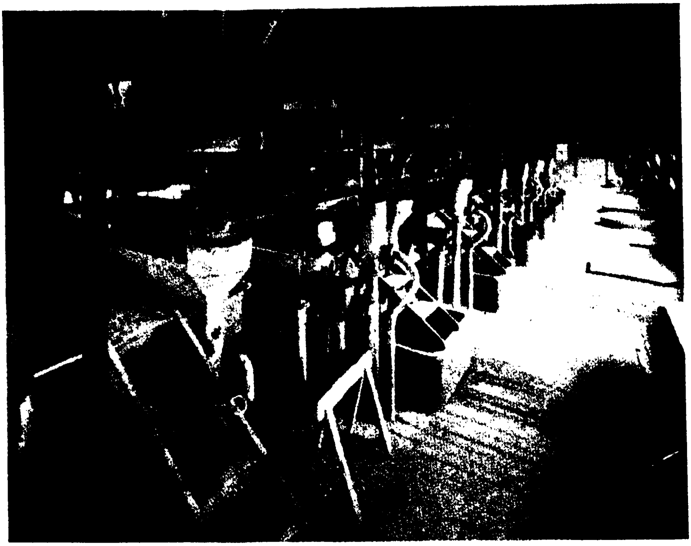
Gathering seaweed for the potato crop, Isle of Skye

Seaweed used as fertiliser in a potato garden at Kodiak, Alaska

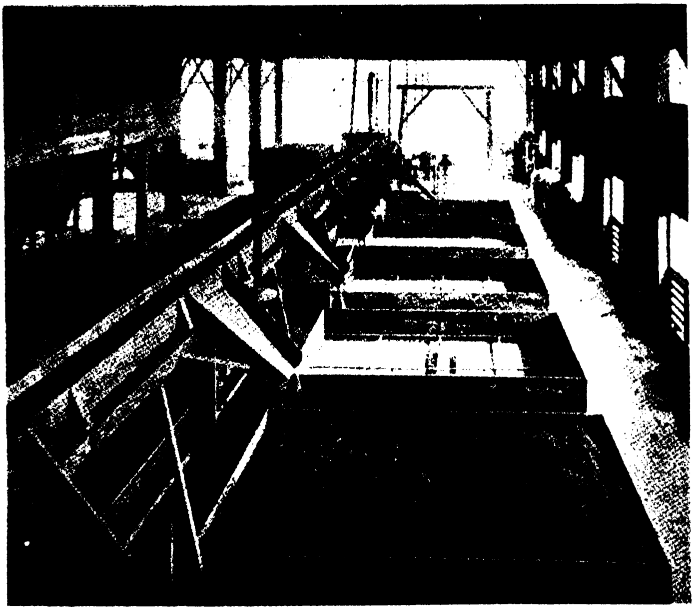
Gelidium latifolium used in Ireland for Agar



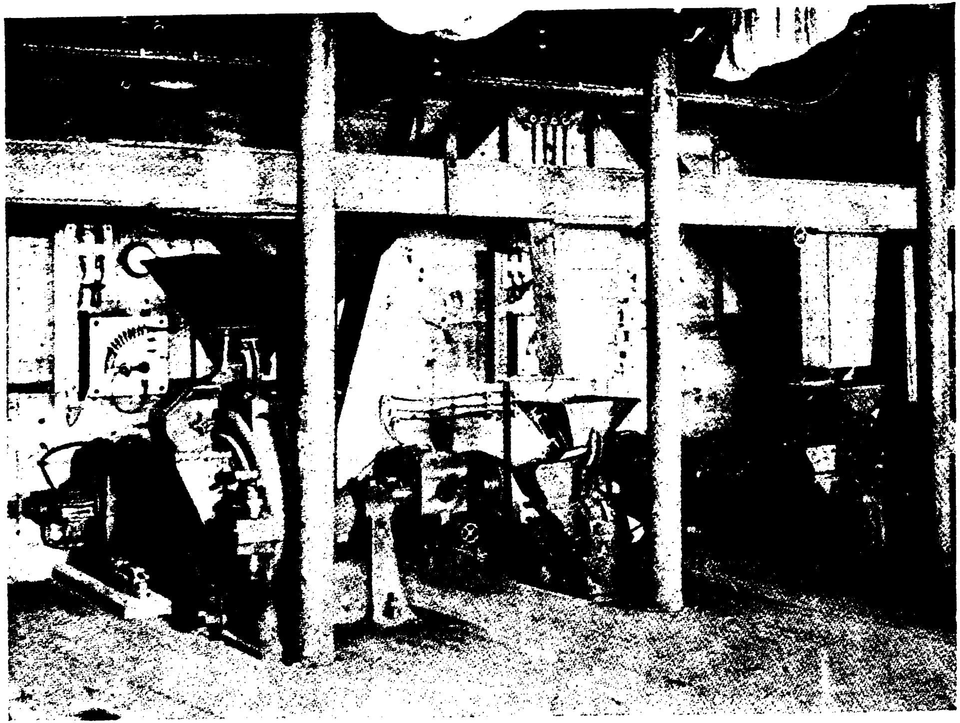
Machine for manufacture of board from algin as used by research workers in Galway



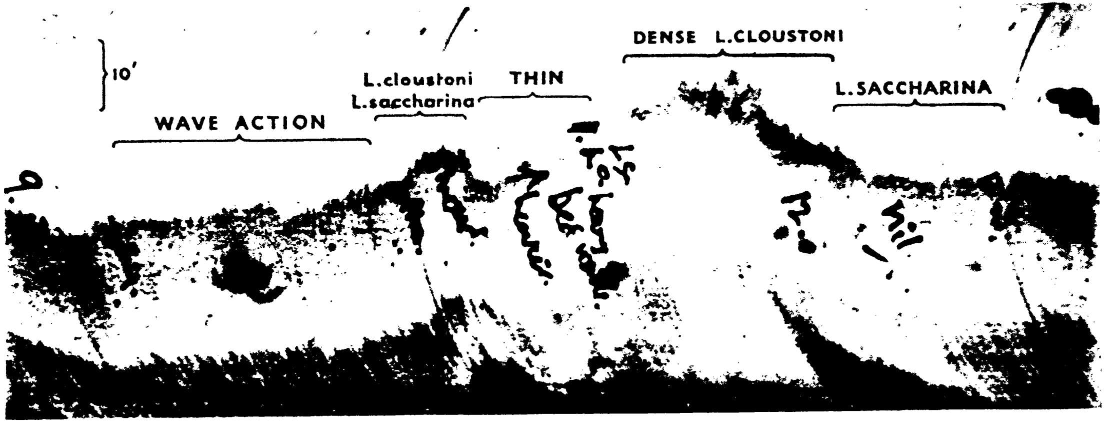
Vats for washing of seaweed in
preparation of algin



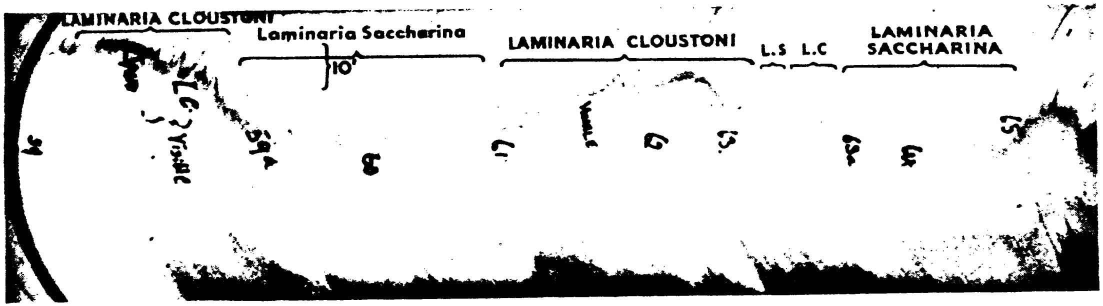
Drying seaweed after washing



Breaking or milling seaweeds

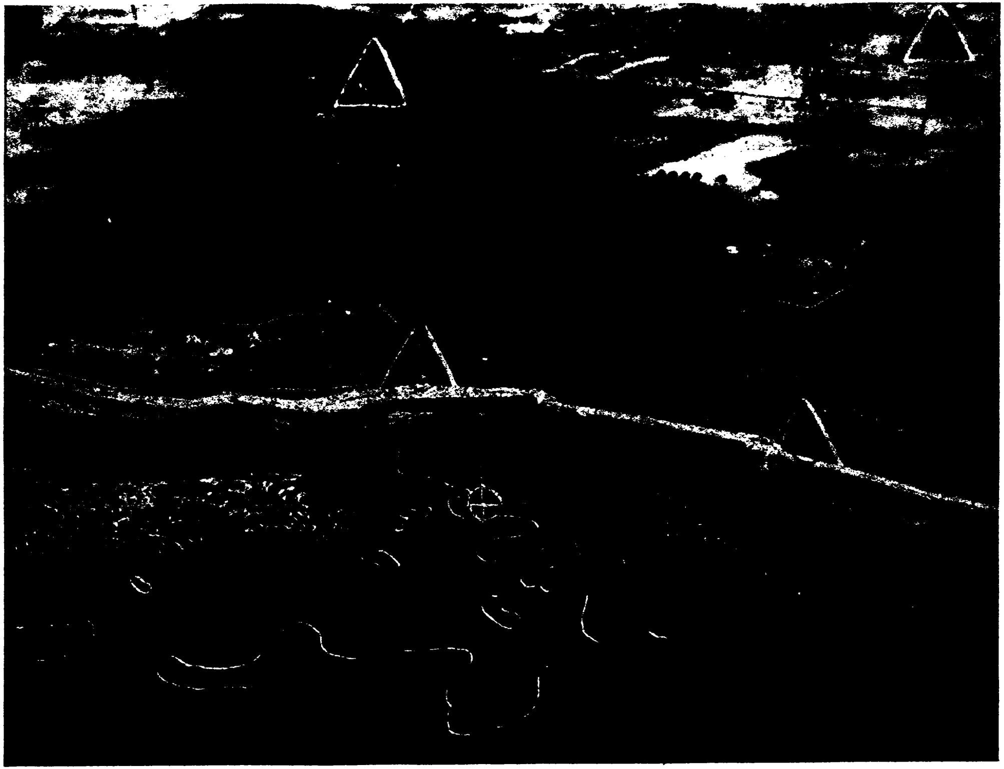


Record with wave action, *L. cloustoni* and *L. saccharina* beds

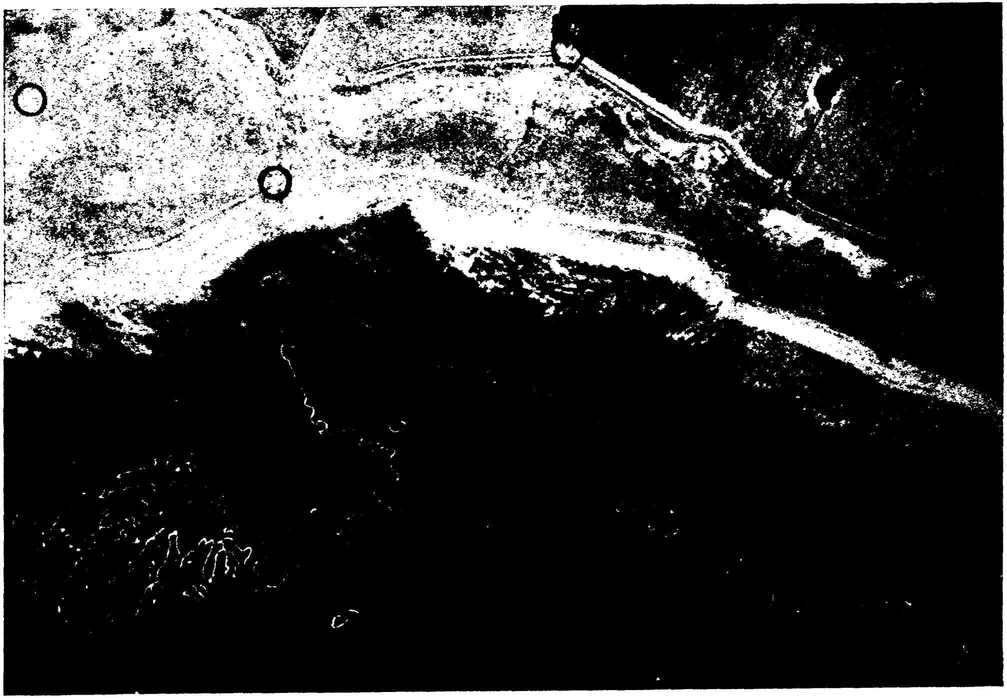


Record of *L. cloustoni* and *L. saccharina*

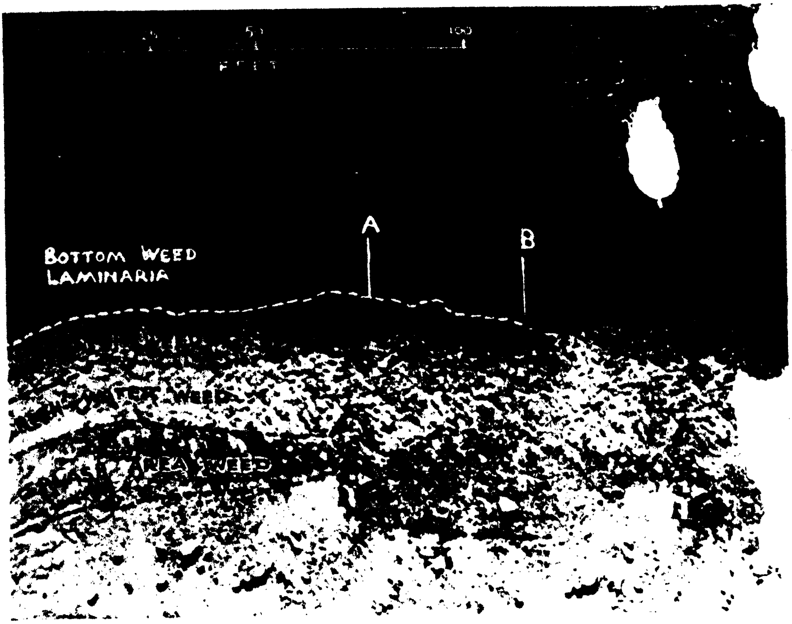
Record from which map in Fig. 52 was plotted



Oblique air photograph of kelp bed

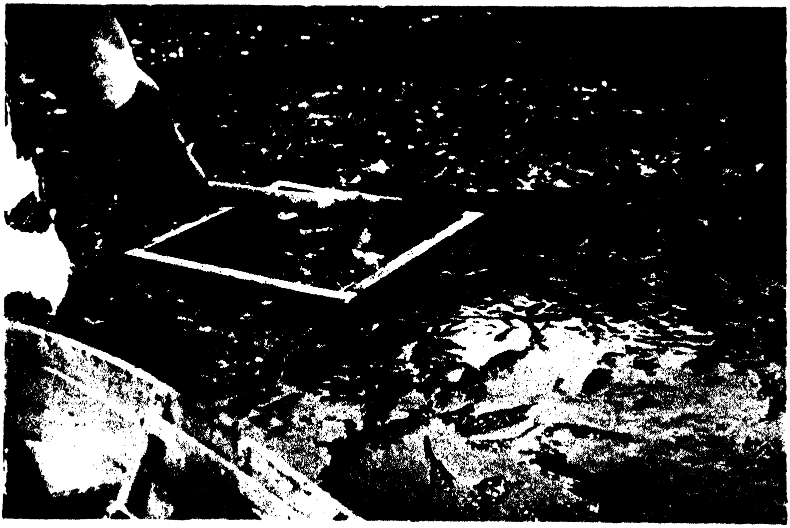


Vertical air photograph of the same kelp bed as Plate 16



Example of the application of air photography to the mapping of rockweed beds

Dense bed of *Macrocystis* off Stewart Island, New Zealand



Cutting a sample square of *Macrocystis* during the New Zealand survey

Bed of *Ecklonia buccinalis* and *Laminaria pallida* in South Africa